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# PORTLAND CEMENT.

BY

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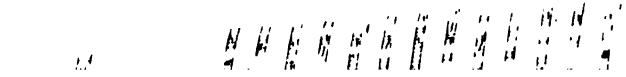

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# EDITORIAL.

The following articles upon Portland Cement were specially written by Mr. Davis, a well-known cement maker, for the benefit of the readers of *The Stone Trades Journal*, in which publication they originally appeared.

In response to numerous requests we have decided to re-issue in a more permanent form the information relating to the manufacture, chemistry and testing of cement which those articles contained.

The author has taken pains to make the science of cement an easy object for study by the general consumer, and the valuable illustrations which further explain the text, will, we think, justify our giving the work a more permanent form than was originally intended.

THE EDITOR.

"THE STONE TRADES JOURNAL" OFFICES,
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LONDON, W.C.

# CONTENTS.


| | PAGE. |
|---|---|
| Introduction .. .. .. .. .. .. .. | 1 |
| Portland Cement—Chapter I. .. .. .. .. | 3 |
| Raw Materials—Chapter II... .. .. .. .. | 11 |
| Mixing—Chapter III. .. .. .. .. .. | 18 |
| Estimation of Raw Materials—Chapter IV. .. .. | 27 |
| Calcining—Chapter V. .. .. .. .. .. | 34 |
| Clinker Grinding—Chapter VI. .. .. .. .. | 42 |
| Chemistry of Cement—Chapter VII. .. .. .. | 49 |
| Test for Weight and Specific Gravity—Chapter VIII. .. | 57 |
| Fineness—Chapter IX. .. .. .. .. .. | 64 |
| Setting—Chapter X. .. .. .. .. .. | 75 |
| Tensile Strength—Chapter XI. .. .. .. .. | 87 |
| Compression Tests—Chapter XII. .. .. .. .. | 99 |
| Soundness and Variation of Volume—Chapter XIII. .. | 103 |
| Specifications—Chapter XIV. .. .. .. .. | 115 |

# LIST OF ILLUSTRATIONS.


| | PAGE. |
|---|---|
| View of Modern Dry Process Works in England | 5 |
| Reservoir Wall in Cement Concrete | 7 |
| Concrete Wall and Footpath | 9 |
| Microscopic Sections of Chalk and Limestone | 11 |
| Raw Material Quarry at Cambridge | 13 |
| Chalk Quarry on the Medway | 15 |
| Quarry in Lower Lias Formation | 16 |
| Wash Mill Employed in the Wet Process | 18 |
| Grit Mill for Wet Grinding | 19 |
| Drying Drum | 20 |
| Tower for Drying Raw Materials | 21 |
| Mixing Machine Used in the Dry Process | 22 |
| Compound Wash Mills | 23 |
| Raw Material Blocks Prepared for Burning | 25 |
| Faija's Dietrich Calcimeter | 28 |
| Michaeli's Calcimeter | 30 |
| Scheibler's Calcimeter | 32 |
| Dome or Bottle Kiln | 34 |
| Dietzsch Kiln | 37 |
| Diagram Shewing Interior Working of the Rotary Kiln | 38 |
| First Rotary Kiln Used in England | 39 |
| Interior of Rotary Kiln Plant | 41 |
| Battery of Griffin Mills | 47 |
| Kominor Mill for Cement Grinding | 48 |
| Laboratory Wash Bottle | 52 |
| Filtration | 53 |
| Drying, Ignition and Fusing | 53 |
| Chemical Balance | 54 |
| Laboratory Apparatus for Evaporation | 55 |
| Hopper for Weight per Bushel Test | 58 |
| Hopper and Bushel Measure | 59 |
| Mann's Gravimeter | 61 |
| Keate's Specific Gravity Bottle | 62 |
| Blount's Volumenometer | 62 |
| Griffin's Specific Gravity Flask | 63 |
| Schumann's Specific Gravity Bottle | 63 |
| Photo Plates of Flour and Residue | 65 |
| Photo Plates of Coarse and Fine Cements | 67 |
| Pats of Finely Ground Cements | 69 |
| Cement Testing Sieves | 71 |
| The Flourometer | 73 |
| Gilmore Needles | 76 |
| Vicat Needles | 77 |
| Goodman's Cement Setter | 78 |
| Amsler-Laffon Apparatus for Testing Consistency | 83 |
| Amsler-Laffon Cement Setting Recorder | 85 |
| Briquette Mould | 89 |
| Arnold Press | 90 |
| Böhmé Hammer | 91 |
| Adie Testing Machine | 93 |

## *LIST OF ILLUSTRATIONS.*


| | PAGE |
|---|---|
| Michaelis Testing Machine .. .. .. .. .. | 94 |
| Faija's Testing Machine .. .. .. .. .. | 95 |
| Sections of Broken Briquettes .. .. .. .. | 97 |
| Faija's Cement Gauger .. .. .. .. .. | 97 |
| Amsler-Laffon Apparatus for Compression Test .. .. | 100 |
| Fairbank's Testing Machine.. .. .. .. .. | 101 |
| Mould for Compression Test.. .. .. .. .. | 102 |
| Attachment for Compression Test with Fairbank's Machine | 102 |
| Contraction Cracks in the Test Pat.. .. .. .. | 106 |
| Expansion Cracks in the Test Pat .. .. .. .. | 107 |
| Deval Hot Water Bath .. .. .. .. .. | 108 |
| Superficial Cracking or " Crazing " in Cement Work .. | 109 |
| Bauschinger's Apparatus for Constancy of Volume Test .. | 111 |
| Faija's Hot Water Apparatus .. .. .. .. | 112 |

# PORTLAND CEMENT.

## Introduction.

THE present period of the German invasion of our cement market is an ominous one for British cement manufacturers. A Portland cement is being put upon our market which in quality equals, if not excels, in some instances, the average product shipped from many of our best known works. The price of the foreign cement is one the English manufacturer is reluctant, if able, to sell at; and large contracts in this country are being secured by our foreign rivals. The history of the manufacture of Portland cement may be put into a very short space as regards the present inferior position of the average English works.

Portland cement was first invented in this country about 1756. Some years later our Continental neighbours started cement manufacture on sound scientific principles. Since this time our foreign rivals have been forging ahead. They have been successful in solving problems of vital importance in the more modern manufacture of a first-class quality product, and at prices which enable them to ship cement, not only to this country but to the very centres of the export and colonial trade which English manufacturers once thoroughly relied upon as their own market.

Although Portland cement was first made in England, our manufacturers now make trips to Germany in search of information. But after visiting Germany we are not satisfied until we have gleaned the fullest information about the use of the Rotary kiln, the latest American success, in the operation of burning the raw materials for the manufacture of cement. Take, now, the different methods of the English, German, and American works in burning the raw materials, and it will at once appear even to the uninitiated exactly where we must look to our laurels. Fuel is a most expensive item in the

manufacture of cement, and the average English works use 8 to 10 cwts. of coke to burn material for a ton of cement. Many German works have greatly improved on this, and can make cement with half the fuel cost by the use of more modern kilns. Then the American works have gone one better, and use about the same amount of fuel as the Germans, but have considerably reduced the amount of labour required for the burning process. So the cost of production has been reduced from about 18*s*. per ton by the English method to about 13*s*. per ton, now possible by the employment of Rotary kilns.

In both cases the cost mentioned is for labour and fuel only, and does not include interest on capital or other incidental expenditure. But the above comparison shows at a glance where the English manufacturer has lost ground. From a standpoint of construction, organisation and operation, combining modern methods of production and general excellence of the finished product, America has, without doubt, furnished an object lesson for English cement makers, and we hear nothing, at any rate to the time of writing, of American intrusion into English cement markets, simply because in the short space of time that he has been manufacturing, the American cement maker can only supply the demand of his own market.

But what will be the position of the English cement trade ultimately? Shall we give our home markets to our foreign rivals? No! We do not for a moment believe that this will be the case. We would prefer to look forward to the time when the English cement maker will generally adopt the most up-to-date process and improve upon it in such a way that he will be first in the field once more; and with this end in view, at least as far as cement is concerned, he was never more active in improving his works than at the present time.

The old-fashioned English methods of cement manufacture have, we hope, had their day, and that it has been such an inordinately lengthy "day" is due to the fact that, up to now, there has been a good demand in the home market for cement, resulting in such a fair profit and interest on the capital expended on the erection of works, that we in England have been satisfied with the extremely unsatisfactory state of affairs which generally ensues from affluence and inactivity. In fact, so dormant have we been that the impression obtained of our foreign rivals' industrial conditions as it concerns cement making is a revelation to us. Speaking of to-day, however, foreign competition in our English market is serious;

and the result is—though surely not too late—we are actually starting on building modern cement works and putting down modern plant in our obsolete factories. It has been stated that the chief causes of our loss of export trading, for instance, are the invincible independence of the English manufacturer, the difficulty it has been in the past to get manufacturers to alter their habits as to chemical proportions, burning or grinding, and that manufacturers have been far too ready to force their experience on their customers. To this we may reply that the English cement maker labours under the necessity of working to the most divergent, multifarious and fastidious specifications, and his what has been termed "independence" may after all only be the not very unnatural desire to point out to prospective customers that the composition or strength in a cement ordered will not yield the results anticipated, or that, as has been known to happen, the manufacturer actually supplies his usual brand of cement, which may be of much superior quality to that asked for by unscientific specifications, and thus perhaps may differ absolutely in composition, fineness, and tensile strength.

To compare ourselves with our German rivals one has to bear in mind the difference between these original and varied specifications, and the standardisation of cement tests, a difference of position which the English maker knows to his cost. Of the making of specifications here in England there is no end, and instead of cement being tested according to lines thoroughly well settled, it is subjected to endless variations of tests by more or less experienced officials.

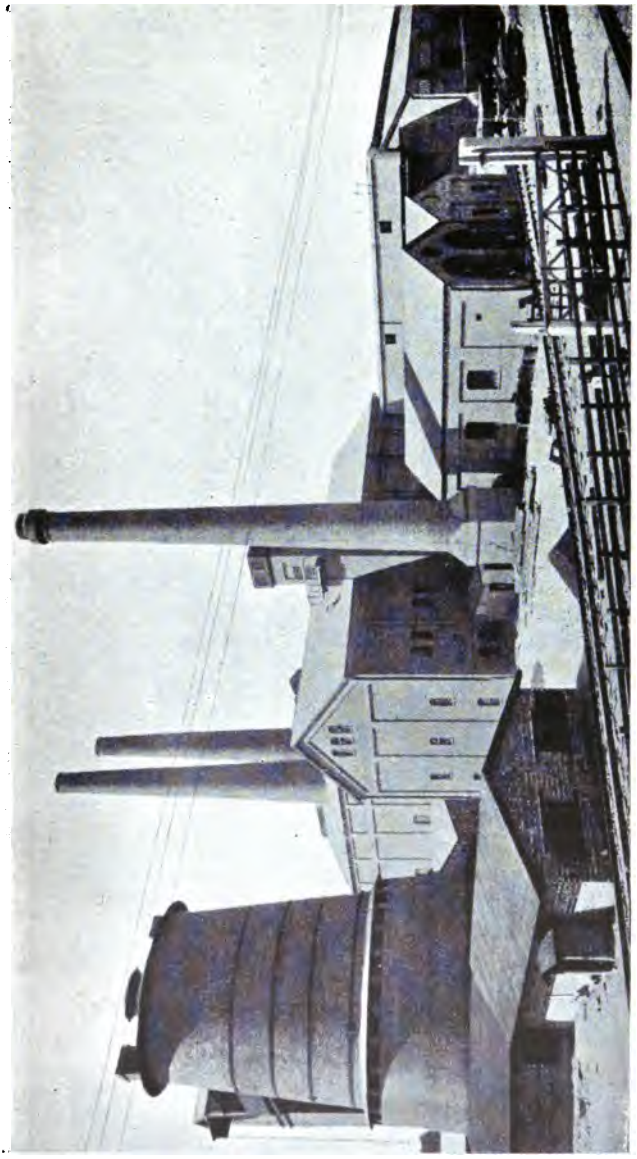
In giving a brief description therefore of the manufacture and testing of Portland cement, one must necessarily include—in fact, mainly adhere to—the methods adopted in this country, but we will also record the progress that has been made in the industry of recent years. It will, then, be our object in outlining the subject to show that it is one not so obscured by technicalities that the idea of manufacturing cement should take on an air of mystery to the average mind, as is so generally found to be the case.

## I.—Portland Cement.

THE increasingly large number of uses to which Portland cement may be applied are doubtless readily attributable to the great strides which have been made during recent years in the science of the manufacture of this invaluable product.

The properties of cement for building purposes are illimitable, and, indeed, speaking generally, its uses are unending. Cement concrete streets and footpaths, with their remarkable neatness and evenness, are being constructed on all sides, and who can fathom the uses of Portland cement now so generally applied in connection with all the extensive engineering works which are day by day being undertaken? With the construction of docks, reservoirs, foundations, and fortifications, the manufacturer sees that his endeavours to produce a reliable quality material are accompanied by a gratifying increase of trade, and it is deserving of comment that the complicated theory of the manufacture and the testing of cements—both scientific processes—has been so thoroughly mastered by the majority of engineers, as we know to be the case. The impetus given to the trade by the use of Portland cement in the chief engineering works of the present day is remarkable, and the engineer has given to this product a place of unchallenged importance.

An increasing and more intelligent knowledge of the possibilities of Portland cement has been followed by the construction of walls, pavement flags, and sanitary houses. These, and numerous other examples of concrete work, afford ample opportunity of studying the subject in its most comprehensive form and its minutest details. On all sides we hear that new work is being accomplished, that fresh discoveries are being made, and improved methods adopted by those who are devoting their energies to the investigation of the subject from its scientific point of view; and with a freer interchange of ideas between manufacturer and user, we may find that even now the uses and application of cement are in their infancy, and will be enormously increased as knowledge extends, and the possibilities of the product are realised.



VIEW OF A MODERN DRY PROCESS CEMENT WORKS IN ENGLAND

Modern architecture, building, and engineering practice demand a high grade Portland cement, possessing great tensile strength, fineness of grinding, uniformity in colour, and particularly a good analysis, thus assuring that all construction work will improve with age and stand sound and strong for whatever period it may be required.

Too much care, therefore, cannot be exercised in selecting a good brand of Portland cement. The Eddystone lighthouse stands to-day not only as a guide to ships that pass in the night, but also as a monument to mark the starting-point of all that we know concerning hydraulic cements.

Smeaton, in 1757, was the first to discover that a calcined mixture of lime and clay possessed the property of hydraulicity, and in 1836 the following tests were published of four of the chief cements in use at that time—

11 days 34·9 lbs. per square inch.
" 17·6 " "
" 30·6 " "
12 days 30·5 " "

but it was not until 1860 that any considerable quantity of Portland cement was made for the general market in England or the Continent.

At the present time a thoroughly sound Portland cement can be manufactured to test as much as 1,000 lbs. per square inch in seven days.

The term "Portland" is limited to a hydraulic cement containing a large percentage of lime, and at once distinguishes the valuable constructive material bearing that title from other cementitious substances. In 1843 a firm of merchants advertising Portland cement stated that "its colour closely resembles that of the stone from which it derives its name," and the material has been known under the name of Portland cement ever since.

It is safe to assume that the Thames Tunnel (1828) was the first engineering work of importance in which Portland cement was used (the price at that time was, by the way, 21*s.* per cask at the works), for there can be no doubt that in its earlier days it was mainly a stucco cement, and it was not until much later that Portland cement acquired the confidence of the engineering profession.

Portland cement of the uniform and reliable quality of to-day, however, is made chiefly from an artificial mixture of carbonate of lime and clay in certain exact proportions. These substances form a compound in the manufactured material of lime, silica, and alumina. It is produced by

calcining the raw mixture at a high temperature and grinding the resultant clinker to a fine powder.

Portland cement takes up water of crystallization in setting, and thereafter hardens in the air as well as in water without

RESERVOIR WALL IN CEMENT CONCRETE.

undergoing any material change of volume. Exposed to the air the set cement hardens principally through the absorption of carbonic acid gas by the liberated lime, and in water it hardens principally through the formation of hydro-silicates out of a portion of those of its constituents that are reacted upon by the liberated lime that dissolves.

The chemical constituents of Portland cement have long engaged the study of experts with the result that many different formulæ have from time to time been put forward as representing a standard composition, only to be contradicted and replaced by others offered by scientists investigating further samples of material.

The generally accepted formula of the composition of Portland cement is X (3 CaO $SiO_2$ + Y (2 CaO $Al_2 O_3$) as representing a correctly balanced material and may be calculated as follows:—the proportion of lime equals 2·8 times the per cent. of silica + 1·1 times the per cent. of alumina.

The total cement production of the world each year may be estimated at 7,000,000 to 8,000,000 tons, of which 2,500,000 tons are produced in Germany, 1,500,000 tons in England, 450,000 tons in France, nearly 1,000,000 tons in Russia, 50,000 tons in Belgium, and a total of 400,000 to 500,000 tons in Switzerland, Austria, Denmark, Sweden and Norway, Roumania and Italy. It is difficult to ascertain the exact production of Portland cement in the United States, but it certainly is not less than 1,000,000 tons per annum.

The chemical properties of cement are constantly undergoing changes from the time the material is ground into the manufacturers' stores until made into a mortar and incorporated into the structure; indeed, these changes continue indefinitely, and our knowledge of the external and internal influences effecting them is little. The aëration of cements—a safeguarding process adopted by engineers for important works—is perhaps advisable so as to eliminate any free lime that may be contained in the material, as an "underburned" cement contains a considerable quantity. Cements such as this, when mixed with water, set quickly, and sooner or later the particles of free lime absorb moisture and change from what is termed "quicklime" (CaO) to a hydrate of lime $Ca(HO)_2$, and the expansion which accompanies this change produces ominous cracks in the hardened cement.

If the cement be exposed to the atmosphere for some time before using, any free lime which it may contain will absorb moisture from the atmosphere and will not then be liable to cause injury to the cement after setting. But this condition is rather the business of the manufacturer than that of the cement user, for a cement made from chemically accurate raw materials, well burnt and finely ground, as all cements should be, will not require any aërating process.

There are many kinds and qualities of Portland cement at present on the English market, and although the following chapters may assist the intelligent cement user in finding the quality of material he is to purchase, yet there are few who make that far more ready enquiry into the manufacture that would so often save the engineer and contractor much inconvenience and expense in the employment of a faulty cement. It is difficult to determine the quality of a cement from the

CEMENT WALL AND FOOTPATH.

actual material as it is delivered on to the work for use, but it is, on the other hand, easy for a cement user to personally investigate the conditions under which is manufactured the material that has to take such an important and responsible part in the great engineering enterprises of the present day.

The Director of Works to the Admiralty adopts a plan which it would be well for all cement users, however small, to copy, and that is, no cement manufacturer is asked to tender for supplies of cement to the Admiralty unless the Department is convinced, by inspection of the works, that the methods of

manufacture adopted are such as would warrant a thoroughly reliable cement being supplied.

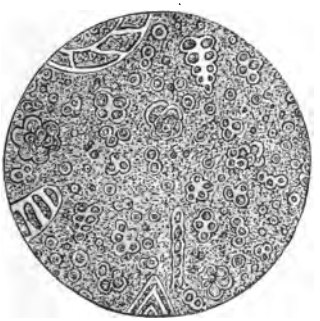
If every cement user were to adopt the principle of enquiry as mentioned above, he would at once be in a far better position to know the actual qualities of the material than is ascertainable by any number of tests, although the latter are equally necessary for verifying results from time to time as the cement is used and the work of construction proceeds.

It is hoped that in giving details of the manufacture and testing of Portland cement the user will be led to recognise the work done by manufacturers to improve their product, and that manufacturers themselves may learn something of the problems which still invite their efforts at solution.

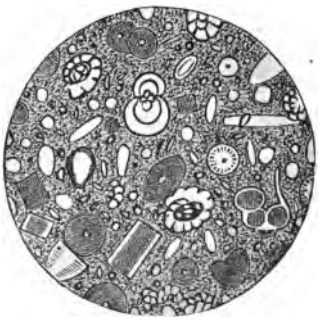
## II.—Raw Materials.

WHAT is known at the present time as "Portland cement" is a product of recent invention, and in its manufacture each year finds pioneer investigators whose aim is the attainment of a commendable and reliable standard material. Theory and result are formulated in the action of ingredients and their proper combining properties, and Portland cement, by showing a steady improvement in quality and a gradual decrease in price, grows as a consequence in practical utility.

In order to make a good cement it is necessary that the



CHALK.



LIMESTONE.

ingredients be very accurately proportioned, and the material be homogeneous. This requires ordinarily the pulverisation of the raw materials, and their uniform incorporation into the mixture in a finely divided state.

The normal composition of Portland cement is within the following limits:—

| | |
|---|---|
| Lime ... ... ... | 60 to 65 per cent. |
| Silica ... ... ... | 20 to 24 per cent. |
| Alumina ... ... ... | 6 to 8 per cent. |
| Oxide of iron ... ... | 2 to 4 per cent. |
| Magnesia ... ... ... | 1 to 3 per cent. |
| Sulphuric acid ... ... | ·5 to 2 per cent. |

According to the nature of the raw materials to be treated, and the process adopted, every manufacturer determines the proper composition within the above limits.

If it were at all possible to find a geological formation of uniform composition containing exactly the right amount of chalk and clay, Portland cement could be made from it by the cheap and simple method of merely burning lumps of the material as obtained from the quarry, and grinding the resultant clinker. But such a material has not been discovered in this country, and it is perhaps hardly likely that it will be, for a variation of even from one to two per cent. of the proportion of carbonate of lime in the raw material for the manufacture, to say nothing of the irregular composition of its other ingredients, is sufficient to at once attack the reliable quality of the resultant cement. The writer, however, recently found a raw material (limestone) deposit in Belgium which made a good quality cement—although varying about 4 per cent. in lime carbonate—from its composition just as the material was quarried. It is true that the natural marl deposits of the Cambridgeshire district very nearly approach the desired combination of chalk and clay, and, unfortunately, in one or two instances the manufacture *is* carried out as stated by burning the calcareous deposit just as it is quarried, and grinding the resultant "clinker" (a large proportion of which is dust) for Portland cement. The unreliable quality of a material so produced is demonstrated by the crudest tests; and, from a scientific as well as from a commercial point of view, where the deposit varies in its composition, as the analyses of chalk marls generally show that it does, such a process of manufacturing Portland cement—a chemical product—cannot be too strongly condemned.

The chalk marls of Cambridgeshire have been proved to be eminently suitable for the manufacture of a first-class quality cement, but the analysis is fluctuating, and this involves the closest observation and the most careful calculation of proportions. The natural deposit is, in the most favourable conditions, found about 2 feet below the surface, and runs to a depth of from 30 to 35 feet.

The carbonate of lime, being in a measure the most valuable and most important ingredient from a cement-making point of view, is shown from various analyses to average 70 to 80 per cent., and the remaining constituents are exactly the amounts of silica, alumina, and oxide of iron required in the manufacture. It is only safe to treat these marls under a

scientific cement-making process. The manufacture should be arranged so that the "lower chalked" marl is intimately

RAW MATERIAL QUARRY AT CAMBRIDGE.

blended with the material containing an excess of lime-carbonate, so as to produce a working average of, say, 76 per cent. The resultant mixture is then ready for proceeding with the further operation of burning.

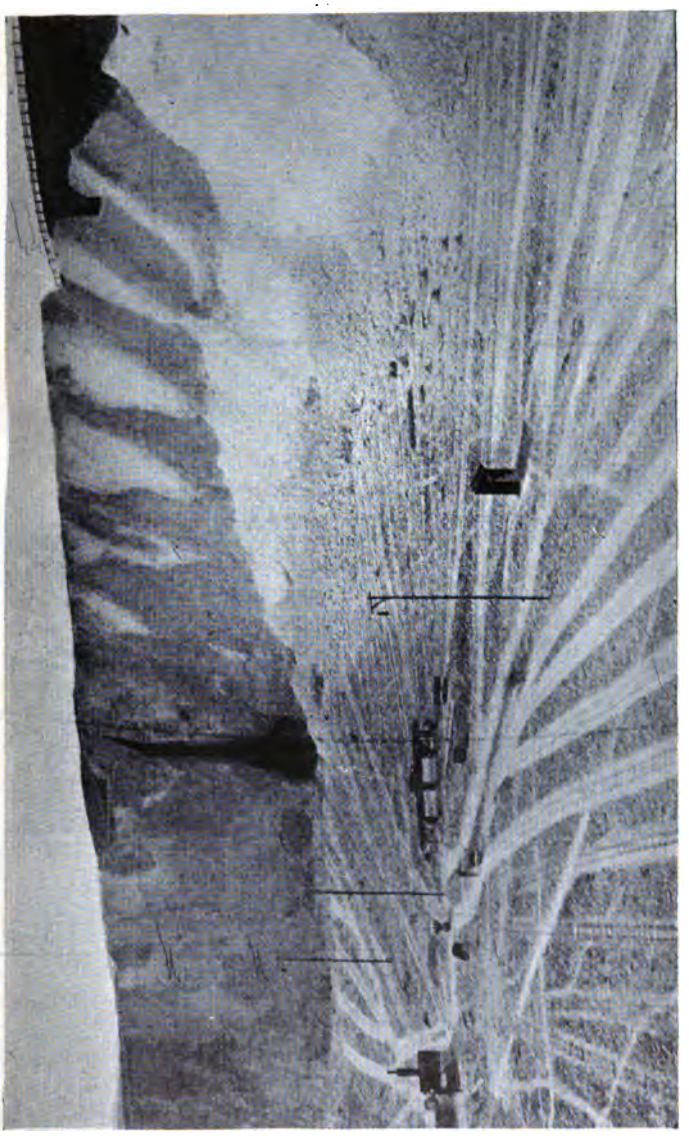
In manufacturing Portland cement, and ensuring its ultimate quality, a fixed quantity of chalk and clay has first to be efficiently and accurately amalgamated, either by the addition of water to the raw materials, or by the fine grinding and mixing of the same in its dry state. The Cambridgeshire deposit is easily and economically dealt with, either by the wet or dry process, and the marl is, as a rule, singularly free from any dangerous or undesirable properties.

With either process of blending the raw materials, say to a fixed 76 percentage of carbonate of lime, the fineness of the minute particles must be such as to allow of the exact chemical change taking place in the burning or calcining operation, and if this preliminary process of mixing the raw materials be not carried out with sufficient thoroughness, failure is bound to be the result, and will at once make itself evident when the material is further dealt with.

In passing to the deposits of the Thames and Medway district—which at this time is the centre of the cement-making industry—Portland cement is made either from a mixture of the chalk and clay of the alluvial formations of the lower parts of the rivers, or from the chalk with flints and the mud principally deposited by the tidal waters which have swept along the shores bounded by the chalk cliffs. This chalk contains about 98 per cent. of carbonate of lime, and the estuary mud is composed of silica, alumina, and iron. The small and objectionable proportion of flint found in the chalk is removed in the wet process of mixing—a ton of water being used for each ton of cement-producing material, the moisture having to be driven off before the further calcining process can take place.

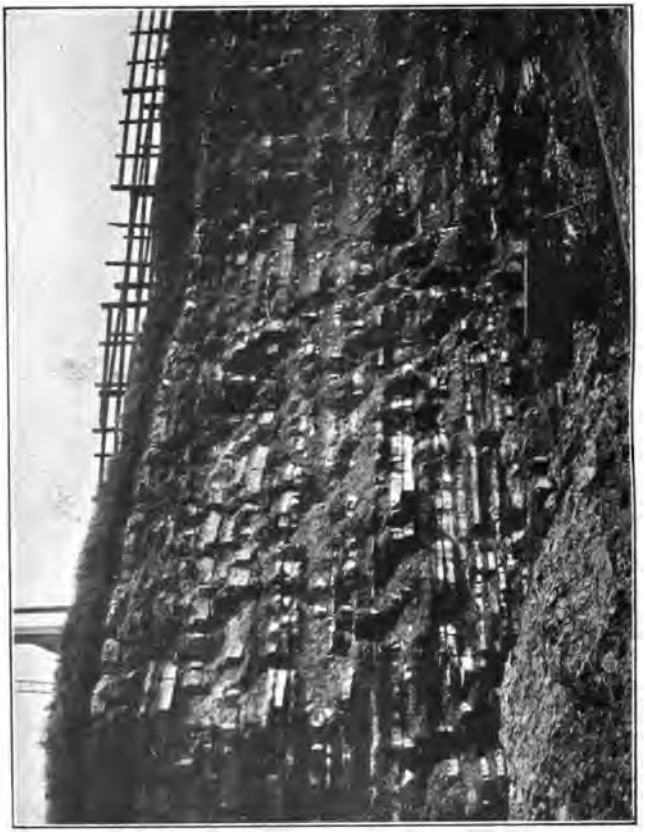
Many of the Southern factories have been erected on the river banks, and a considerable advantage in the manufacture is derived from being thus enabled to quarry the chalk at the back of the works, whilst the mud is brought from the lower reaches of the river by barges.

In the cement-making districts of the Midlands, the Lias formation of limestone and shale is successfully treated, and the thin layers of these materials with their considerable variation in composition must be very accurately and efficiently dealt with. The deposit may be found to an



CHALK QUARRIES ON THE MEDWAY.

appreciable extent in other parts of England, but the preponderance of shale in proportion to the limestone (which is generally found to contain only 78 to 85 per cent. of carbonate of lime) renders the cost of working excessive, because of the



QUARRY IN THE LOWER LIAS FORMATION.

amount of material not required in the manufacture, which has either to be made into bricks or wasted. The raw materials here are ground in their dry state for the preliminary operation of mixing to the required percentage of lime-carbonate, and when carefully dealt with, a good quality cement is manufactured.

In other instances in the North-east of England, the raw

material for the manufacture of cement are obtained by bringing chalk from the London district by water, and mixing with the clay found on the site of the works.

The mud, shale, or clay forming the respective admixtures to the chalky materials should be mainly siliceous, and as free from sand as possible. Highly siliceous clays containing silica up to 75 per cent. give mixtures which stand the great heat of the kiln without fusing, and produce a clinker which is comparatively easy to grind, and which generally yields a slow-setting cement which shows a steady increase in tensile strength over long periods. Magnesia and sulphates present in any considerable percentage are objectionable in the manufacture of cement, and iron oxide and alumina in the raw material are perhaps just necessary.

The two materials, or the necessary chemical combination, indispensable for the manufacture of cement are but rarely found upon the same site. Some works, however, are favoured with these conditions, and it is only necessary to examine the localities of the most successful works in the country to see how invariably it is the case that, according to the facility with which they command the raw materials, so have their successes been assured.

It will be seen then, that, given chalk and clay, it is next in importance that these materials shall be treated with a full knowledge of the all-important chemical and mechanical operations which alone can secure the manufacture of a reliable article.

## III.—Raw Materials—Mixing.

THE mechanical blending of the raw materials for the manufacture of Portland cement is a stage requiring the utmost technical skill, and the time has now gone by when this responsible duty was left to the ordinary workman to perform by his rule-of-thumb methods. The mixing process in the most successful cement works is now carried out under the closest supervision of the works' chemists, and the manufacturer thus well knows that the finished product is not

WASH MILLS EMPLOYED IN THE WET PROCESS.

exposed to the continual dangers and failures which were so common in the earlier stages of the manufacture.

The chalk and clay must first be reduced to the utmost fineness, either by the addition of water, which breaks down the cohesion between the particles and leaves the material in a very finely divided state, or by the more mechanical process of grinding when dry. The physical properties of the respective materials to be dealt with will generally determine which method of reduction is to be adopted.

The ingredients are then mixed in certain exact proportions, and the accuracy with which those proportions are estimated, and the mechanical efficiency with which the process of admixture is carried out, are the first essentials in the manufacture.

As originally practised in this country, the mixing of raw materials was carried out by the " wet " process, by which the chalk and clay are ground and mixed in a " wash mill," where a large amount of water is added. The thick chalky liquid is then allowed to settle in large reservoirs. The wash mill, even

now extensively used in the manufacture, consists of a brick pit, some fifteen feet in diameter and five deep, in which revolve a series of harrows for breaking up and mixing the two ingredients in their wet state.

At the present time Portland cement is required to pass high tests as to tensile strength, to attain which it is necessary to raise the proportion of carbonate of lime in the mixture to a point so near the limit that the resultant cement would be likely to be unsound if the two materials were not carefully weighed into the wash mill in such proportions as to give in the ultimate product the proper percentage of lime, as well as to insure its satisfactory quality.

A grit mill is also used for wet grinding, and this consists essentially of a long grinding drum made of steel and protected against wear and tear by interchangeable cast-iron

"KRUPP" GRIT OR TUBE MILL FOR WET GRINDING.

plates. The drum contains a large number of flint-stones, and its interior is of easy access through two or more manholes.

The raw mixture, previously reduced by the wash mill, flows through a simple straight pipe or a bent pipe and through the hollow journal on the front end near the gearing into the grinding drum. After being thoroughly ground by the flint-stones, the material is discharged through the hollow journal at the opposite end into a trough, which conducts the raw material to the drying chambers.

Another method of wet mixing—one now, perhaps, more generally carried out—is that which consists in passing the mixed chalk and clay from the wash mill in a semi-plastic state between edge-runners or millstones. Under these conditions, the necessity for the large amount of water used in the first-named method, and which must all be dried off before the

material can be burned, is partially obviated—the thick, pasty material being carried on to the further machinery of reduction, where the operation of amalgamation is completed. This wet grinding serves a double purpose: it not only reduces all the chalk to such a size that the necessary intimate mixture may take place with the clay, but it also assists the actual mixing, which it renders more uniform.

Disadvantages in the above methods of mixing have, however, led to the adoption of the "dry" process, which, in brief, is as follows: The materials are ground together in the dry state, mixed, and finally pressed into bricks or blocks, ready for the subsequent stages of manufacture. A dry process plant comprises machinery or kilns (such as the "tower" or drying drum here illustrated), for the preliminary drying of

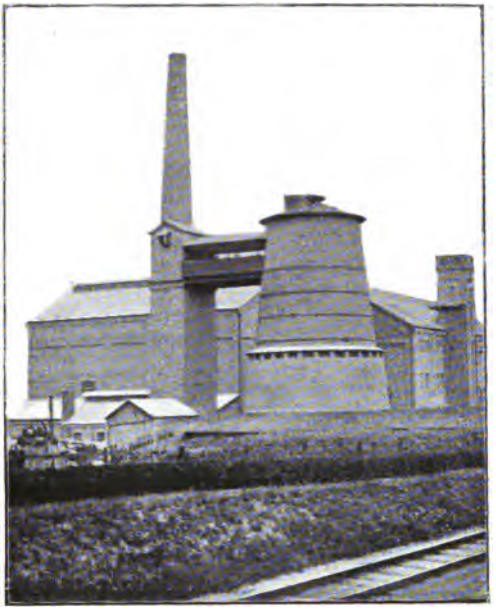
DRYING DRUM FOR THE DRYING OF RAW MATERIALS FOR THE DRY PROCESS.

the chalk and clay as it is brought from the quarry; apparatus for the reduction of the two materials to an impalpable powder, or, as we might aptly term it, "flour"; and mixers for the storage and mechanical mixing of the "flour" until passed as chemically accurate. The raw material has then to be evenly and regularly moistened, in order to give the necessary amount of "bind" when being pressed into convenient blocks for burning.

Another system of treating the raw materials by a combined drying and burning process has lately been introduced into this country from America, in the shape of the Rotary kiln; but this we will explain in detail in another chapter.

In comparing the advantages and disadvantages of the two methods of mixing—the wet and the dry—it must be pointed out that in many instances, perhaps in most, the nature of

the raw material determines the process to be adopted. Some materials can only be mixed by the wet method, others only by the dry, while a very few (of which the Cambridge deposit is one) lend themselves to both. Where this is the case, the dry method is undoubtedly the one which, from its many advantages as compared with the wet, is the most strongly to be recommended, since it allows of a more scientific preparation of the raw materials, the mixing of the marl



TOWER FOR DRYING RAW MATERIALS WHEN QUARRIED.

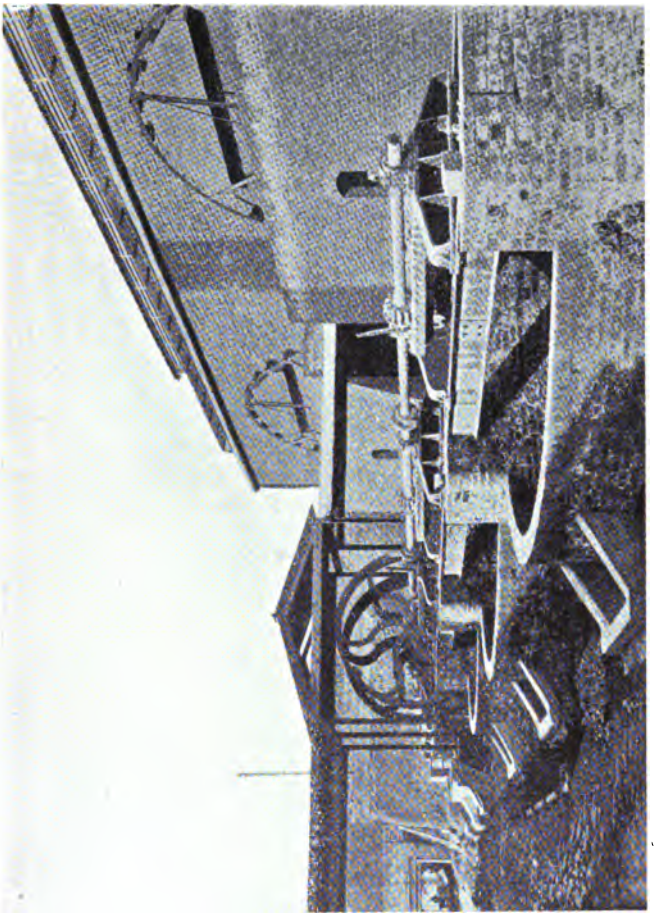
in drying after its analysis in the quarry, the grinding to an impalpably fine flour, and finally the holding and storage of a quantity of material in the mixers, where it is not allowed to pass until again chemically tested, and the chemist assured that the mixture is one calculated to make the best possible cement. Such a process can insure the bulk of the raw material being within ·2 per cent. of the required proportion of carbonate of lime, as compared with a variation of from 1 to 2 per cent. by the wet process. Again, by the dry method, the raw materials, after mixing, are pressed into bricks all of

equal size and weight, and so the firing process results in an evenly-burnt clinker, whereas by the wet, the material, after

MIXING MACHINE USED IN THE DRY PROCESS.

the moisture has been drawn off, is broken in pieces of varying size, and thus is filled into the kiln. The consequence is that

the large lumps are often under-burnt, and the small lumps over-burnt, thus greatly deteriorating the cement and necessi-



COMPOUND WASH MILLS.

tating a careful sorting of the output from the kilns before the final grinding for cement.

The dry method, again, has been proved to be better adapted for the finer grinding of the raw material, a scientific examination of the nature and composition of which will enable the investigator to ascertain the necessary degree of fineness

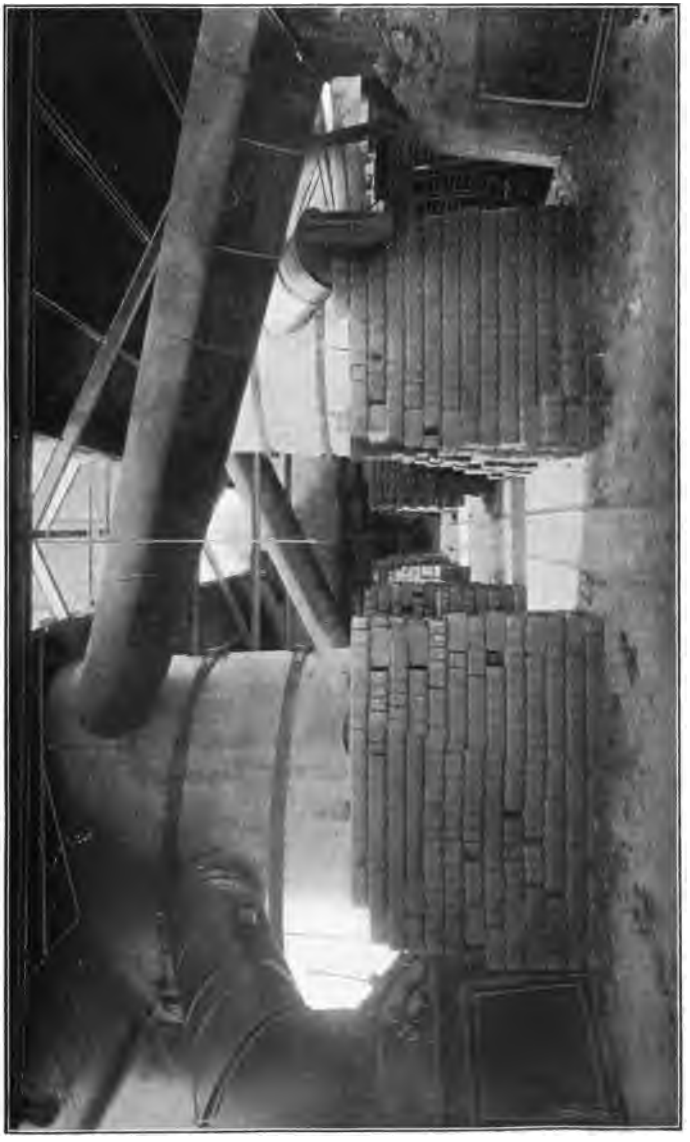
—whether it be ground so as to pass through a sieve having 5,776 meshes to the square inch, or through one with 10,000 in the same area.

If the reduction of the ingredients be complete, and, chemically considered, the lines laid down are strictly adhered to, the resultant cement is an absolutely perfect product, an assertion which no tests, however severe, have yet been able to disprove. The composition of the raw material mixture is ascertained by analyses and tests, undertaken by the works' chemists at frequent intervals, and the carbonate of lime (familiarly known by its chemical formula, $Ca\ CO_3$) should be kept within one-half per cent. of the quantity found to produce the best cement. This percentage of lime carbonate varies in different works according to the many geological formations contributing to the manufacture, but roughly, a combination of from 74 to 77 per cent. of chalk will produce a cement of fair quality. When the remaining proportion of clay runs too high (or the percentage of lime carbonate falls below 74) a compound is obtained which, in the burning process, will fuse at a temperature lower than that required for the production of a sound clinker, thus rendering it useless. On the other hand, an excess of chalk (above, say, 77 per cent.) will allow a mixture to sustain the highest temperature in the kiln without risk of fusion, but the resultant clinker would be of very doubtful quality because of its "blowing" tendencies when ground for cement.

Again, a variation in the amount of carbonate of lime, even to one-half per cent., is found to appreciably alter the tensile strength of a cement. A series of tests bearing on this were recently made, and it was shown that from a perfectly mixed raw material of 76·5 to 77 per cent. $Ca\ CO_3$, a cement was produced the tensile strength of which at seven days was 780 lbs. per square inch, and at twenty-eight days 940 lbs. With a mixture of 76 to 76·5 per cent. lime carbonate, the strain was 610 lbs. in seven days, and 800 lbs. in twenty-eight days, and with a mixture of 75·5 to 76 per cent. $Ca\ CO_3$, 520 lbs. in seven days and 730 in twenty-eight.

The mechanically-mixed raw material prepared in the ordinary course of manufacture may analyse as follows:—

| | | | |
|---|---|---|---|
| Silica | 16·72 | per cent. | |
| Alumina and oxide of iron | 6·10 | ,, ,, | (Clay) |
| Undetermined | ·57 | ,, ,, | |
| Carbonate of lime | 75·50 | ,, ,, | (Chalk) |
| Carbonate of magnesia | 1·11 | ,, ,, | |



RAW MATERIAL AFTER MIXING AND PREPARED INTO BLOCKS FOR BURNING.

And from such material, if properly treated in the further stages of manufacture, a cement testing at 600 lbs. per square inch in seven days should be produced.

It will thus be seen how the mixing process primarily determines the quality of the resulting cement, and if the manufacturer is to turn out a product of reliable quality, the supervision of this branch of the industry is of paramount importance.

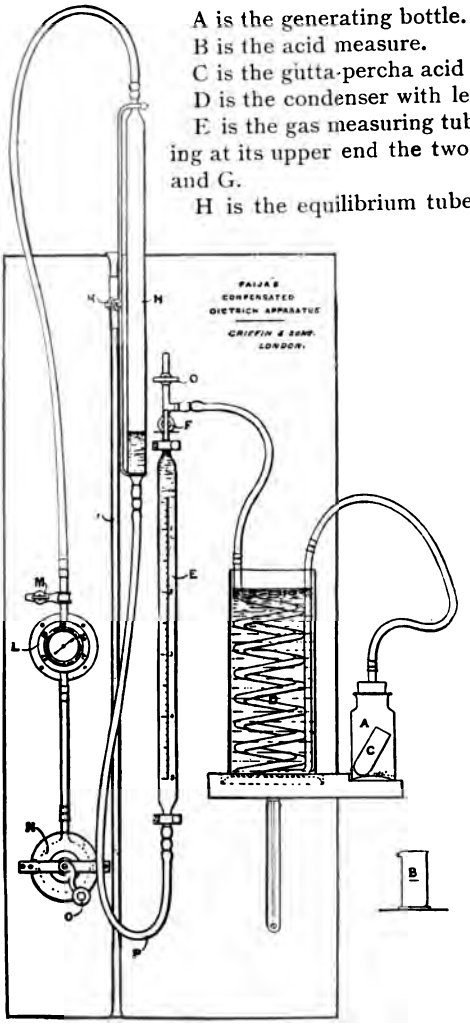
## IV.—Estimation of Raw Materials.

In no stage of the manufacture of cement is it necessary to be so chemically accurate as in the estimation of the proportion of carbonate of lime to that of silica and alumina in the raw materials. If the ingredients of the mixture are not of the exact and necessary proportions before passing on to the succeeding stage of manufacture, no effort on the part of the manufacturer and no scientific operation can bring the resultant cement up to the standard it might have attained if the ingredients had been mixed in the proper proportions. It is, therefore, necessary for the manufacturer to carry out an incessant check at least upon the determination of the calcium carbonate (provided the raw material mixture is of normal constitution), and methods must be adopted of accurately testing the mixture with speed and facility, so often each day has the test to be carried out.

The two methods in general use are (1) by the calcimeter, and (2) by titration. There are so many calcimeters at present in use that it is perhaps only necessary to describe one or other of the best known instruments, such as Scheibler's calcimeter for the volumetric estimation of calcium carbonate, and the Faija's Compensated Dietrich apparatus for the volumetric determination of carbonic acid gas. Both these are illustrated here and act by the indirect gas method in which the carbonate of lime is decomposed by acid, and the evolved carbon dioxide gas collected in a suitable apparatus and measured; for since the carbonic acid bears a fixed proportion in the calcium carbonate, the percentage of lime can be calculated from the volume of gas given off. By the titration test the calcium carbonate is decomposed by a measured quantity of standard nitric or hydrochloric acid, and the excess of acid determined by titration with standard alkali. This latter test is of a more technical description and necessitates the careful preparation and standardising of solutions by qualified chemists.

To revert to the calcimeters, however, we will give a description of the Faija's Dietrich instrument.

A is the generating bottle.
B is the acid measure.
C is the gutta-percha acid tube.
D is the condenser with lead coil.
E is the gas measuring tube, having at its upper end the two taps F and G.
H is the equilibrium tube, which




FAIJA'S DIETRICH CALCIMETER.

may be moved up and down, and secured in any position by fixing it on the rod I, by means of the thumb-screw K.

L is the barometer, to which is attached on its upper side the tap M.

N is an india-rubber ball, attached by a tube to the barometer, which ball may be compressed or expanded by turning the handle O, thus adjusting the pressure in the instrument.

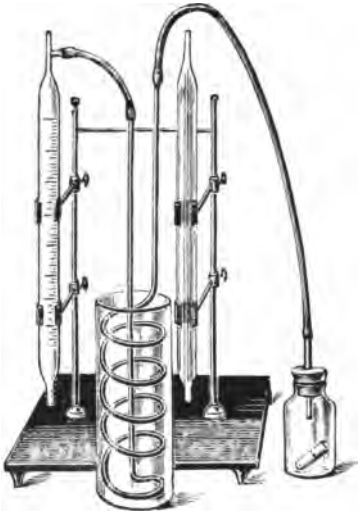
To set up the instrument it is first necessary to secure it firmly against a wall, taking care that the tubes E and H are perfectly vertical. Then attach the india-rubber tube P, connecting the lower ends of tubes E and H. Tube H should then be lowered until its upper neck is a little above the lowest reading on tube E, a funnel inserted in the neck of H, and the tube filled with water until the water rises up to the lowest reading in tube E. When filling with water, the two taps F and G should be open, and as air is likely to accumulate in the india-rubber tube P, this should be squeezed and pressed until the air is all expelled. The water used should be distilled water, and in order that all air may be expelled from it, it should be boiled and allowed to cool before pouring into the instrument. Then attach the other india-rubber tubes, as shown in the drawing, put the stopper into the generating bottle A, close taps G and M, and see if the instrument is tight. This is ascertained by placing the equilibrium tube H in such a position that there is a difference of several inches in the level of the water in the two tubes E and H, and noting the reading of the level of the water in tube E; if the instrument is tight, the water will remain at this level for an indefinite period. If, on the other hand, the water in E rises or falls, some of the joints are not tight, and they must be made tight by binding them with thin brass or copper wire. The condenser D should be filled with water.

### *To Work the Instrument.*

Having ascertained that the instrument is tight, the mode of working is as follows:—

First remove the cork from the generating bottle A, and take out the acid tube C, then open the taps F, G, and M. Elevate tube H to such a height that the water in tube E is exactly level with the mark immediately under tap F, and secure it there by turning the thumb-screw K. Weigh out the quantity of carbonate of which it is desired to determine the carbonic acid it contains, and place it in the generating bottle A. Measure out the proper quantity of acid to use in the measuring glass B, and pour it into the acid tube C. Wipe the outside of the acid tube C, so as to be sure that no acid

has run down the side, and insert it, with a pair of tongs, into the generating bottle A. Re-insert the stopper in the generating bottle A, taking care that it is secure and tight. Close tap G, and take hold of the thumb-screw K with the left hand and slack it, at the same time keeping tube H approximately in its elevated position. Now take the generating bottle A in the right hand, and incline it so that the acid runs out of the acid tube C, on to the carbonate in the bottle A, and as the gas is generated, lower tube H, so as to keep the water in tubes E



MICHAELI'S CALCIMETER FOR ESTIMATION OF CARBONIC ACID.

and H, approximately at the same level. Continue shaking the bottle while the gas is generating, and be sure that all the acid has run out of the acid tube C. Place the generating bottle A into the water in the condenser D; this is to cool the gas, which might have been heated by the handling of the generating bottle A, down to the temperature of the water in the condenser D. Having left it there for a minute or so, remove it, and again shake it, and note if any more gas is generated. When all the gas is generated, which is indicated by the water in tube E remaining in a constant position, close the taps F and M, turn the handle O, actuating the ball N, in either one direction or the other, so that the pressure in the

barometer is diminished or increased, and it indicates the normal pressure of 29·92 inches, or 760 millimetres, which is shown more distinctly by the heavy line. Adjust tube H so that the water in it is exactly level with the water in tube E, and take the reading of the level of the water in tube E. This reading is the amount of gas developed at the standard pressure, and simply requires correction for temperature, which may be ascertained by tables already prepared.

When using the instrument the thermometer should be placed and left in the water in the condensing vessel D, as it is the temperature of this water which governs the temperature of the gas, but it is as well to try and adjust the temperature of this water to approximately the temperature of the atmosphere of the room in which the instrument is worked.

Before commencing an experiment, the reading of the barometer should be ascertained, and if above 29·92 inches or 760 millimetres, the ball N should be compressed, so that by turning the handle O, and allowing it to expand, the pressure in the barometer will be decreased. If, on the other hand, the barometer is below 29·92 inches, or 760 millimetres, the ball N should be left fully expanded, so that by turning the handle O, and compressing it, the pressure in the barometer will be increased.

The essential portion of the Faija's apparatus for the determination of carbonic acid gas consists in the addition of a barometer to the equilibrium tube, the pressure in which, and in the gas-generating tube, may be adjusted to a standard pressure.

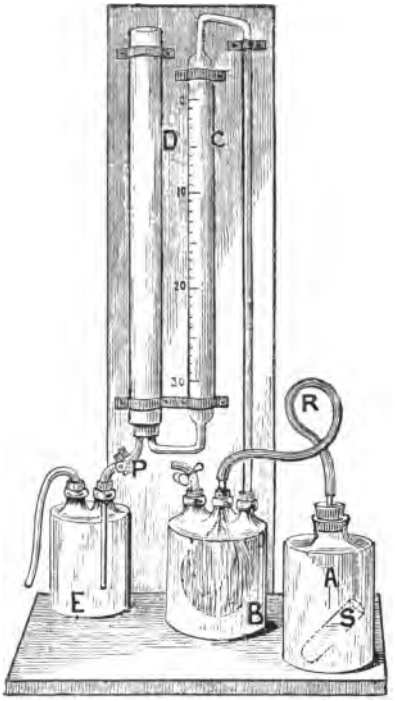
By this arrangement, temperature is the only factor which it is necessary to consider when the volume of the gas has been ascertained by the reading of the instrument; and for easy use with this instrument complete tables have been arranged, so that the operation of testing raw materials only occupies a few minutes.

This variation of the well-known Dietrich and other apparatus has been designed to obviate as far as possible the disadvantages entailed by the difference in volume of gases due to variation of temperature and barometric pressure, necessitating in all instruments designed for their volumetric determination a considerable amount of calculation.

The Scheibler's calcimeter here illustrated consists of the following parts. A small bottle A provided with a perforated stopper. In the bottle is placed a tube S, of gutta-percha or glass. Another bottle B, provided with three openings in its

neck. The central opening of the bottle contains a firmly fixed glass tube, which connects at the one end with A by means of the flexible rubber tube R, and on the other, inside the bottle B, with a very light india-rubber bladder.

The left-hand opening is controlled by a pinch-cock on a piece of rubber tubing. The right-hand opening connects B




SCHEIBLER'S CALCIMETER FOR THE VOLUMETRIC ESTIMATION OF CALCIUM CARBONATE.

with the measuring tube, which is an accurately graduated glass cylinder C, of 150 c.c. capacity. Another glass cylinder D serves to regulate the pressure of the gas measured in C and a tube P passes through a stopper into the water reservoir E, and is connected with D and controlled by means of a pinch-cock.

For determining, then, the amount of carbonate of lime in the raw material mixture, a small sample, finely powdered, is

placed in the bottle A. The tube or cup S is filled with 10 c.c. of dilute hydro-chloric acid and placed also in the bottle.

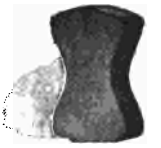
Shake the bottle A so that the acid gradually mixes with the sample, and release the cock P in order that the water which has been previously filled into the cylinders D and C may be released as the gas in C displaces the same; keep the water in D on an exact level with C. Then take the reading on C and compare the volume of gas given off from the sample with the results from testing a standard sample of pure calcium carbonate (Iceland spar).

For example, take ·5 gram pure calcium carbonate, and say the gas registers 18 c.c. on the cylinder C, and say ·5 gram of the mixed raw materials for the manufacture gives 13 c.c. of gas; the result is $\frac{100 \times 13}{18} = 72{\cdot}2$ per cent. carbonate of lime in the sample.

The apparatus for estimation is always placed in the laboratory, where direct sunlight cannot fall upon it, and is also protected from any other heat, so that the results are not affected by these conditions.

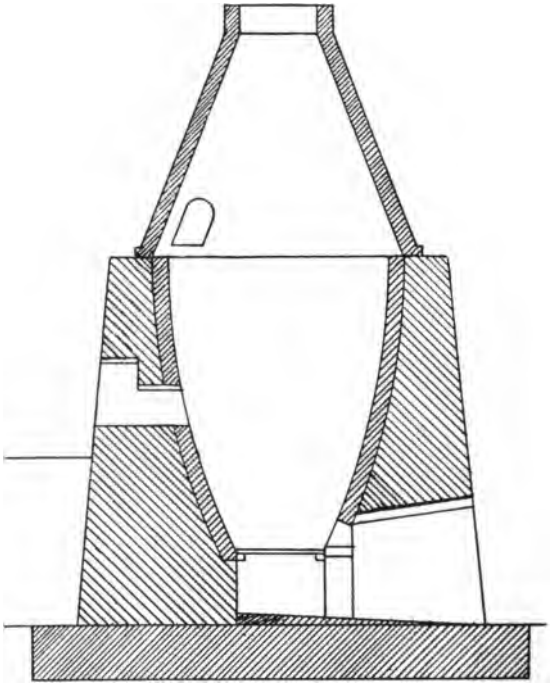
Although other methods can be adopted for estimating the carbonate of lime in raw materials, those described above are found to be sufficiently accurate for general practical purposes, and little or no technical skill is required in their manipulation.

If the raw materials are found to vary in analysis, the testing takes place, in a well-appointed establishment, as the materials are quarried, and the proportions are again corrected before the mixture is passed for the succeeding process of calcination—a stage, again, entirely dependent upon the accurate performance of these chemical tests, and a due appreciation of the meaning and value of their results.



## V.—Calcining.

Among the kilns for burning the raw material in the manufacture of Portland cement there are the Dome or Bottle kilns, the Chamber kiln, and the continuously working kilns

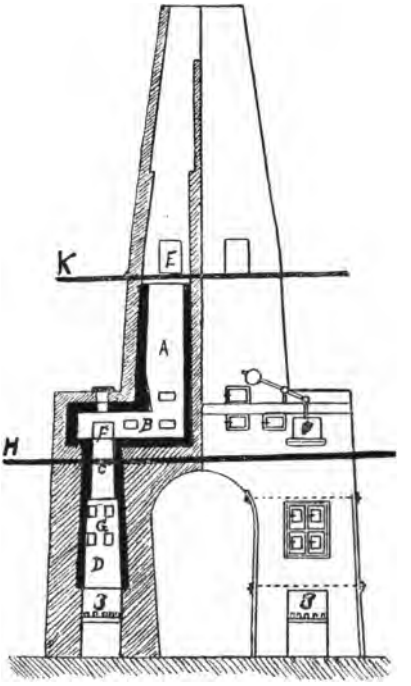


The Dome or Bottle Kiln first used in Cement Manufacture.

of the Hoffman, Dietzsch and Schneider types; and, lastly, the more modern Rotary kiln.

The common intermittent Dome kilns were originally the only type employed in the industry, and are still, to some

extent, in use. Coke is used as fuel, and the consumption amounts to about 40 per cent. of the weight of clinker produced. Continuous kilns are costly to construct, and require skilled labour for their operation. These kilns are, however, very economical of fuel, and since, moreover, the calcining process is much more regular, a better cement is made. Without, however, dealing specifically with the various

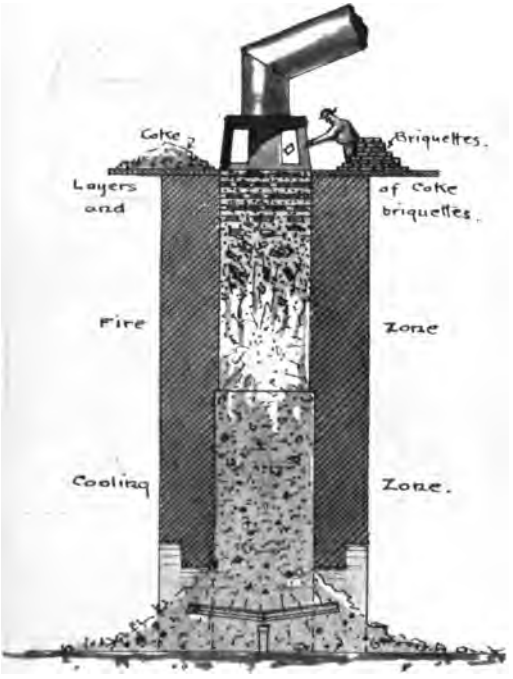



DIETZSCH KILN.

advantages or otherwise of the above variety of kilns, we will proceed to the more general principles of this stage of the manufacture, that is to say, the burning of the raw material.

As before stated, convenient blocks of the accurately blended chalk and clay are prepared, and in working the Dome and Chamber kilns (those most commonly used in this country) the first step in loading is the careful arrangement of the coke upon the faggots placed on the bars of the kiln and which are

used to start the fire. The kiln is then loaded up with alternate layers of raw material and coke, until filled. The attendant burners arrange that the quantity of fuel in the bottom layers of the kiln is greater than in the succeeding layers, and as the loading of the kiln proceeds, the layers of raw material and fuel

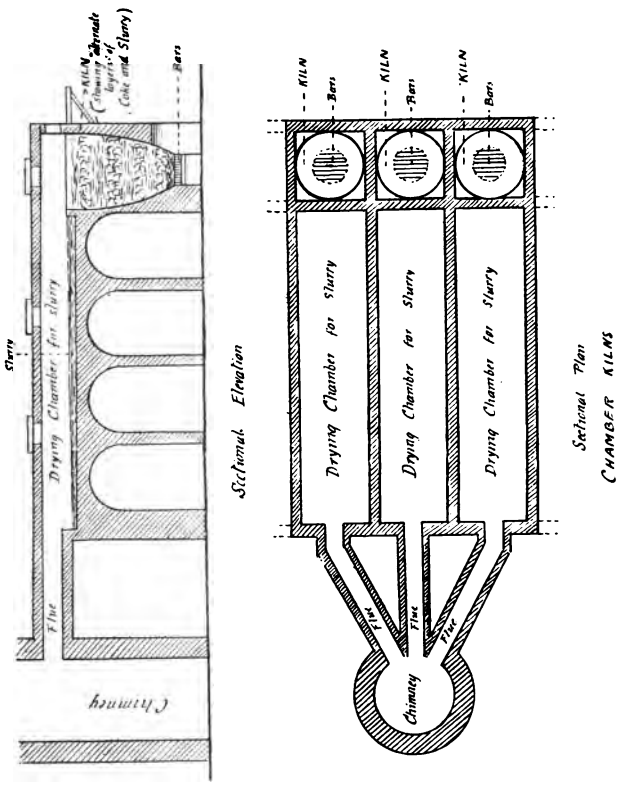



A SECTION OF A "SCHNEIDER" KILN.

also are slightly reduced in thickness towards the top. By this means the desired heat is distributed more regularly over the kiln when it is fired, and in the conversion of the mixture of carbonate of lime and clay into cement clinker the following changes take place:

When the coke becomes ignited by the firing of the faggots

the moisture from the raw material is expelled. With the subsequent red heat the carbonic acid gas is given off, and the final stage in the burning is approached when the heat is increased to almost a white heat of 1,800° to 2,000° Fahr., causing the material to change into a state of slight vitrification. Layer




after layer of the raw material blocks are thus calcined into what is termed "clinker," and with the two "intermittent" kilns above mentioned this process goes on until the whole kiln full is burned through and the clinker cooled down. When cool the unloading of the kiln takes place.

With the "continuous" kilns now used in England—most of which are mentioned above—the heat is kept up by the regular

feeding of raw material, together with the coal or coke used for fuel. The principal difference between what may be described as the old method referred to above, and the continuous kilns here mentioned, is, that instead of burning the kiln right out, cooling, and drawing it empty each time, the burning of the kiln rarely ceases (except for repairs), thus showing considerable economy in the fact that the cold air is travelling up through the burnt clinker, which it cools at the bottom of the kiln, and is at the same time itself heated on its way to the fire zone. After leaving the fire zone, in the form of heated gases, it parts with the greater portion of its heat to the raw material that is travelling downwards (on its way to the fire zone), and through which it passes, now comparatively cool, on its way to the chimney. This is proved

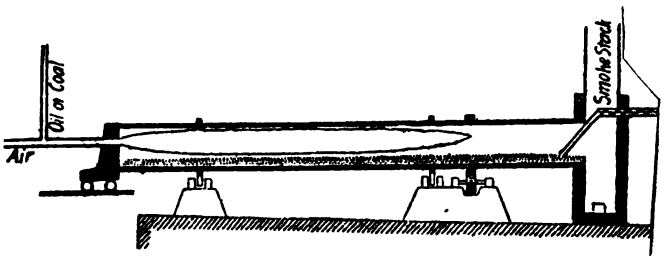
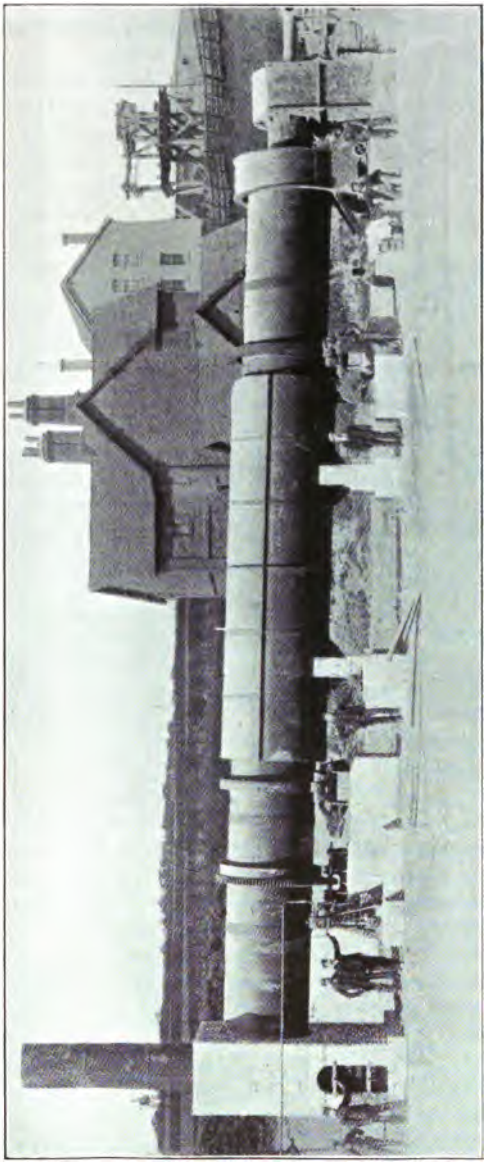



DIAGRAM SHOWING THE INTERIOR WORKING OF A ROTARY KILN.

by the low temperature of the gases when they reach the chimney, the reduction being so great that although the temperature must have been fully 2,000° Fahr. at the fire zone of the kiln, the hand may easily be held in the gases leaving it. There is no doubt that a considerable saving of fuel (some 50 per cent.) is effected by the adoption of the "continuous" type of kiln, for the constant cooling and heating of the dome and chamber kilns previously mentioned (the interval occurring between the unloading and loading) is so much fuel wasted.

In working the "Dietzsch" (continuous) Kiln, illustrated on page 35, the raw material blocks are loaded on the floor-level K, into the opening E, and the chimney A is thus always full. On the working floor H the blocks are drawn by the kiln burners over from the stage B by long shovels, and dropped into the fire zone C, and after each layer of raw material is placed, it is covered with a layer of good quality nutty coal, and the loading door F is closed. The burned material then



FIRST ROTARY CEMENT KILN TO BE SUCCESSFULLY OPERATED IN ENGLAND.

passes down to the bottom of the kiln, and the clinker is drawn at J. The operations of loading and drawing the kiln proceed simultaneously.

Other kilns of the "continuous" type, such as the "Schneider" kiln here shown, are worked on similar lines—that is, the layers of raw material and fuel are fed into the top of the kiln at the same time that the clinker is drawn from the bottom. The fire zone occupies the middle third of the cylindrical building, the layers of raw material and coke being contained in the upper portion, and the clinker in the lower.

The Dietzsch and Schneider kilns are not so much used in this country as they are in the more up-to-date establishments on the Continent. The modern Rotary cement kiln, by which more than 75 per cent. of the cement is produced in America, though it is but little used in England, consists of a slightly inclined steel cylinder usually about 60 feet in length and 6 to 7 feet in diameter. This kiln was originally patented in England in 1869. As tried, however, in this country in 1885 it was a failure for cement burning; but as developed and improved by American engineers, the Rotary kiln was employed with more favourable results, and is now universally used in that country.

The kiln is lined with fire-brick, and the long cylinder is mounted on rollers and slowly rotated by gearing. Finely ground soft coal is now used for fuel, and this is introduced into the kiln through a blower or fan by a jet of air issuing under a pressure of 60 lb. per square inch, taking its hot air from a clinker cooling drum. The cement-making material is fed in continuously through a pipe at the upper end of the cylinder in the form of either liquid mud or dry powder according to the process adopted for mixing. Descending gradually, and meeting with the heat generated by the perfect combustion of the finely ground coal fed into the cylinder from the opposite end, it parts with any water that may be present, becomes heated to redness as it approaches the centre of the cylinder, loses its carbonic acid, forms little rounded balls which reach a nearly white heat in the lower third of the kiln, and finally issues at the lower end as well-burned clinker in grains about the size of a pea.

The operation is a continuous one, and with proper care under- or over-burning may be avoided. The hot clinker from the kiln is cooled either by a stream of water or by being elevated to cooling towers.

The Rotary kilns are not economical in fuel, as they require

40 to 45 lbs. of coal to produce 100 lbs. of clinker, and the greatest problem that confronts the manufacturer is the devising of some means for the cheaper burning of clinker. The price of coke, however—the fuel used in the old-fashioned kilns to the extent of 8 to 10 cwts. of coke to a ton of cement—has advanced so much that the cost of cement production has greatly increased; and further, the supply is so limited that a coke famine is not unlikely at any time. Thus, the Rotary kiln has an immense advantage in

INTERIOR OF ROTARY KILN PLANT IN ENGLAND.

being independent of a fuel which has now attained such fictitious prices. In the matter of labour, too, the Rotary kiln is decidedly economical. The feeding of the kiln with raw material and fuel being automatic, and no labour in "drawing" the clinker being necessary, a saving of some 2*s.* to 3*s.* per ton is effected on the finished cement. Thus, the Rotary kiln marks, and indeed, may be said to have created, a period of development in the production of Portland cement.

The proper degree of burning is indicated by the formation of a dense greenish-black clinker. Light-burned clinker is brownish and soft, while over-burned clinker is fused and slag-like. Long-continued burning, excess of clay, or

imperfect raw-mixing causes the clinker to "dust" or fall to powder on cooling, and this powder shows little or no hydraulic properties. This defect is much more common in vertical kilns than with Rotary kilns, as the quick burning and rapid cooling of the latter process is most beneficial to the cement.

A great responsibility is attached to the proper calcination of the raw materials, and just as the primary blending of the chalk and clay can make or mar the quality of the cement, so may the burning of the material destroy all that is valuable in the finished product. If the heat is too high in the kiln, the resultant material is useless as a cement; and on the other hand, if the heat be not sufficient, the necessary chemical changes in the raw material do not take place, and a similar unsatisfactory result is obtained.

It will be seen, therefore, that to obtain the heat in the kiln for the critical stage of slight vitrification of the raw material requires experience and care. Unfortunately, the present process of burning is not scientific, and too much attention and study cannot now be given to this important stage in the manufacture of Portland cement.

## VI.—Clinker Grinding.

THE succeeding and final stage in the process of manufacture (after the calcining of the raw material) is the grinding into an extremely fine powder of the clinker which comes from the kilns, and it is this process which has perhaps exercised a larger proportion of ingenuity than either of the preceding processes.

Until about ten years ago the grinding was almost invariably carried out by millstones—indeed, in most of the older works in the Thames and Medway district the French buhr stones are used still; but as the requirements of cement users become more stringent with regard to the fineness of the powder, so more economical means have to be found in the designing of new machinery.

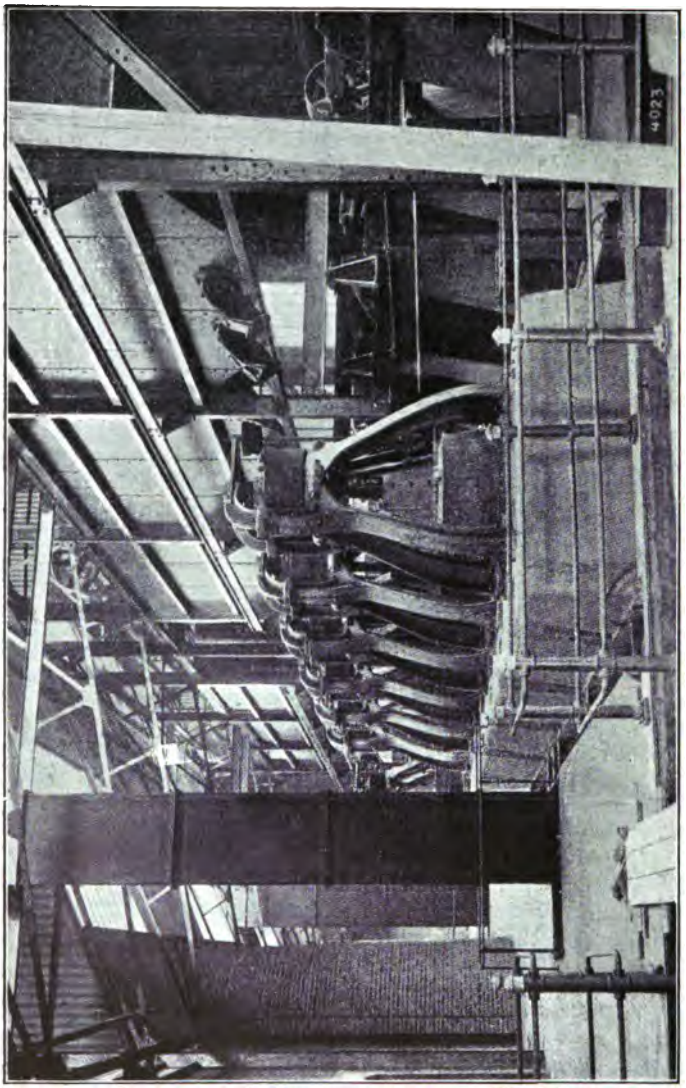
There is no doubt that the grinding of cement by millstones requires a considerable amount of care and watchfulness which, if neglected, adds materially to the cost of manufacture.

They are indeed a never-ending expense, not only in general wear, but in the continual "dressing" of the stones which must be done by expert millers.

It has been stated that the cementitious quality of Portland cement ground by millstones is generally superior to the cement ground by machinery, the stones being supposed to produce an angular rough grain; but upon examining the different samples of cement ground by various methods, it is observed that the difference in the shape of the grains is slight indeed. The assertion is a fallacy.

In the better-equipped and more modern works the preliminary grinding of cement clinker is carried out by the ball mill (see p. 46), and from this mill the coarsely-ground material is conducted to a tube mill which finishes the fine grinding previous to storing the cement. The ball mill consists of a cylindrical grinding drum, mounted on a steel shaft running through it and provided with a tightly-closed sheet-iron casing. The grinding drum is composed of overlapping steel grinding plates, in one half of which holes are

bored for the ground material to find its way through on to the fine sieve externally surrounding the drum, and through




VIEW OF THE INTERIOR OF PORTION OF NEW WORKS, SHOWING BATTERY OF "GRIFFIN" MILLS.

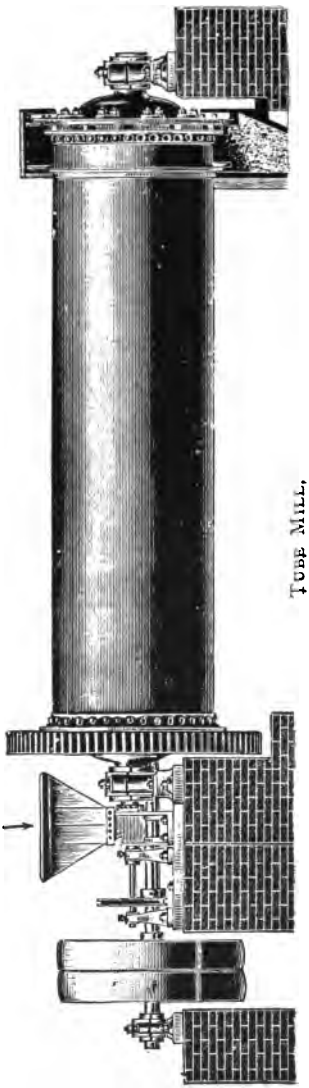
which the somewhat coarsely-ground cement passes and is conveyed to the tube mills for finer grinding. The crushing action of the ball mill is caused by the revolving of the drum, which contains a number of steel balls of various sizes, between which the clinker is crushed and pulverised.

For the finishing process—the fine grinding proper—the tube mill is employed, which grinds by means of the small round flint stones contained within it.

The tube mill consists of a wrought-iron revolving cylinder with hollowed pivots at both the feed and delivery bearings, and is about one half full of rounded flint stones. The coarsely-ground cement is fed from the ball mill into one end of the tube mill, and the rotary action of this mill, similarly to the ball mill, finely pulverises the cement as it passes through the falling flint stones to the delivery end.

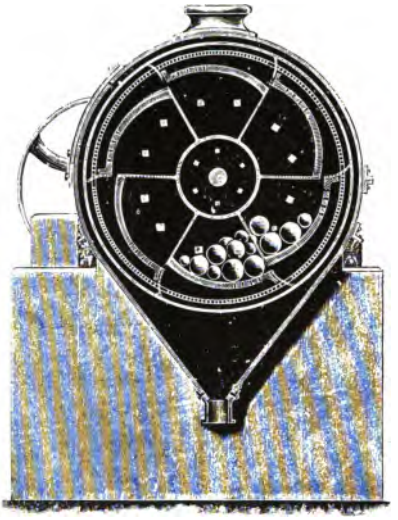
The finished cement is ground sufficiently fine to pass through a 76 by 76 mesh sieve with about 2 per cent. residue, and although finer grinding is rarely demanded by the trade, it can be readily accomplished by the manufacturer if necessary.

The cement clinker produced by the rotary kiln mentioned in a previous article is of very small size and exceptionally hard in substance, so



TUBE MILL.

that with the employment of this type of kiln we again have improvements on the above machinery in the shape of grinding mills specially suitable for dealing with this different form of clinker. The grinding mills adaptable for use with clinker from the rotary kilns are the "Griffin" mills—now greatly used in American works—and the "Kominor" mill. The "Griffin" mill takes the product as it comes direct from the rotary kiln, and the pulverising is done in one operation, and is discharged from the mill in the form of a finished product without the aid of any auxiliary sifting or separating device. The "Kominor" mill is the latest development of the ball mill, and

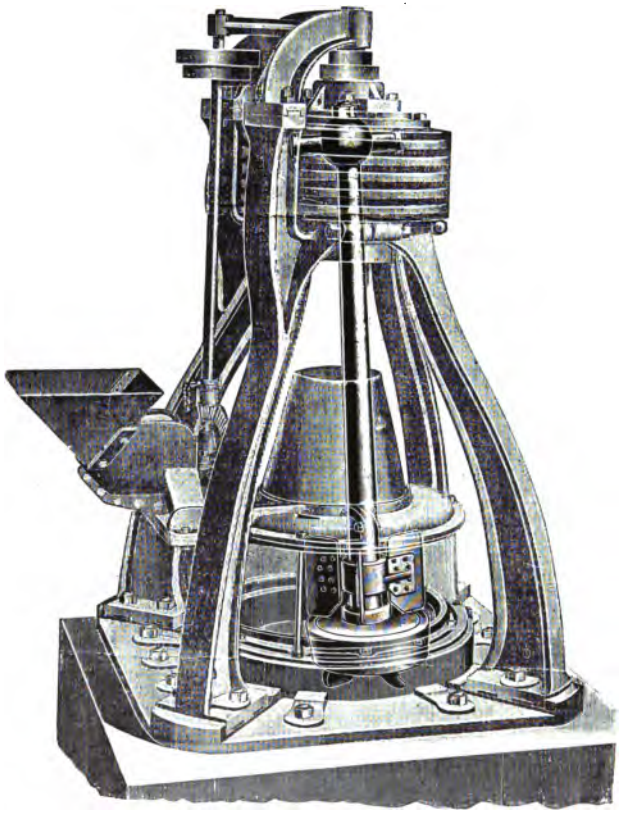


VERTICAL SECTION OF BALL MILL.

combines the crushing action of the balls with the "flouring" action of the tube mill.

The fineness to which a cement is ground determines chiefly its usefulness for constructional purposes; for when a finer cement is mixed with the aggregate to be used in concrete it gives a higher average strength than that mixed with a coarser-ground cement. A fineness of 90 to 95 per cent. passing a 100 by 100 mesh sieve is generally attained in American practice. There is, of course, a point beyond which it is not economical to carry the fine pulverising of cement

since the same result can be obtained by using slightly richer mixtures on the work, but what this point is must be determined by experience. At present the general cement user is ignorant of the special utility of a very finely-ground



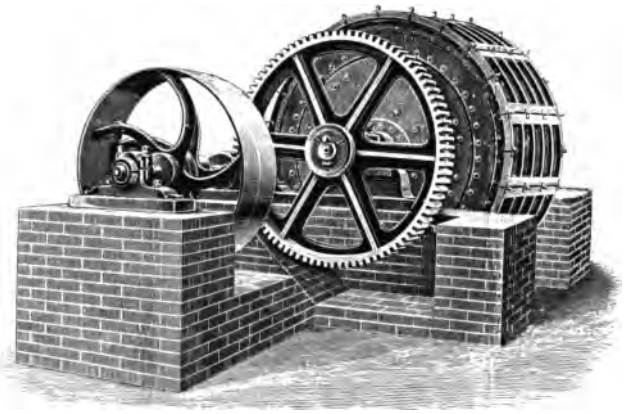
"GRIFFIN" MILL ARRANGED FOR DRY PULVERISING.

cement, and the manufacturer placing such a material on the market will perhaps receive more blame than praise.

The qualities of cement as regards tests of grinding are, however, dealt with in another chapter.

After the clinker has been ground to the requisite fineness

into cement the finished product is conveyed to the manufacturers' stores, where it is kept in bulk for a period, previous



"KOMINOR" MILL FOR GRINDING CEMENT.

to delivering to customers, in bags of about two hundredweight each, or in casks for exporting.

## VII.—The Chemistry of Cement.

THE chemical analysis of cements, if taken in conjunction with the mechanical and physical tests, affords much desirable information in the selection of a good quality material; indeed, it is almost necessary that both the chemical and mechanical examination of a cement should be made before a positive pronouncement of quality can be given, and when both have been ascertained the suitability and efficiency of a cement for any given purpose can be at once accurately determined.

There is no standard method for the analysis of Portland cement, and chemists vary considerably in their estimation of the constituents. This may be seen from the following results of the analysis of a sample of cement as carried out by the different methods of eighteen American experts for a committee enquiring into the uniformity in the analyses of materials pertaining to the Portland cement industry.

| | Silica. | Alumina and Iron | Lime. | Magnesia. |
|---|---|---|---|---|
| Variation from | 19·18 | 9·32 | 62·01 | 2·52 |
| to | 21·56 | 11·36 | 64·30 | 3·13 |

The chemical constituents of a well-made sample of Portland cement may be as under:—

| | Per cent. |
|---|---|
| Carbonic anhydride ... ... ... } | |
| Water ... ... ... ... ... } | 1·22 |
| Silica ... ... ... ... ... ... | 21·04 |
| Alumina ... ... ... ... ... } | |
| Oxide of iron ... ... ... ... } | 9·92 |
| Lime ... ... ... ... ... ... ... | 64·04 |
| Magnesia ... ... ... ... ... ... | ·99 |
| Sulphuric anhydride ... ... ... ... | 1·81 |
| Potash ... ... ... ... } | |
| Soda ... ... ... ... } and loss | ·98 |
| | 100·0 |

The percentages of silica, alumina, oxide of iron and lime may vary to the extent of 1 or 2 per cent. from the above figures and still constitute a good sound article, but magnesia and sulphuric anhydride should never greatly exceed the percentages given.

Silica, lime and alumina must be considered the essential elements of the cement as they combine in the kiln at a clinkering temperature to form compounds having special properties in relation to the effect that water has upon them.

These compounds—silicate of calcium and aluminate of calcium—as they come from the kiln, and until they are wetted to form concrete, are perfectly anhydrous; that is, they are free from water, or, in other words, have no water chemically combined in their molecules. They are, however, capable of forming a chemical combination with water, and in that condition are spoken of as hydrated silicate of calcium and hydrated aluminate of calcium.

Now the peculiarity of these two compounds is that when in the anhydrous condition they are more soluble in water than when in the hydrated condition. The effect of this is that when wetted with water to form concrete, a portion of the anhydrous substance dissolves in the water; it then slowly combines with the water to form the hydrated compound, which, being insoluble, crystallises out from the solution and concretes the whole mass into a solid block. As the solubility is but slight, this reaction takes place slowly, and it may be weeks or even months before it is complete.

This property is known as hydraulicity, and a hydraulic substance is one that will set under water or by the action of water.

The great aim of the cement maker is, therefore, to produce the maximum amount of these substances in his cement. For if on the one hand there is too much lime in the mixture a portion of it remains uncombined, and is a source of danger to the cement, as free lime expands and crumbles to dust on being hydrated, or "slaked" as it is commonly called, thus injuriously affecting the strength and stability of the concrete; if on the other hand there is too much silica and alumina in the mixture, other compounds are formed which have no hydraulicity.

The function of the oxide of iron in the mixture is to act as a flux in the kiln and cause the silica and alumina to combine with the lime at a lower temperature than they would without its intervention, and after that object has been effected the

iron appears to play no further part. Its combinations are not hydraulic and consequently have no concreting power.

The other constituents of cement—magnesia, sulphuric anhydride and the alkalies, potash and soda—are non-essentials.

Magnesia is simply an impurity in the chalk, and, generally speaking, the lower the proportion of it contained in any cement mixture the better cement it will make.

A small quantity of sulphuric anhydride is frequently useful in checking a too rapid setting of the concrete, but it should not exceed 2 per cent.

The composition of cement is largely affected by the ash of the coke or whatever fuel may have been used for calcination and which is ground up and combined with the finished material. Coke ash chiefly consists of insoluble silicate of alumina and iron, and as it takes about eight cwt. of coke to calcine a ton of cement in the intermittent kilns generally adopted in England, and 3½ cwt. of coke in the continuous kilns, it is obvious that the remaining fuel ash has a considerable effect on the ultimate analysis of the cement. For instance a sample of coke ash (about 10 per cent. of the bulk) may analyse as follows:—

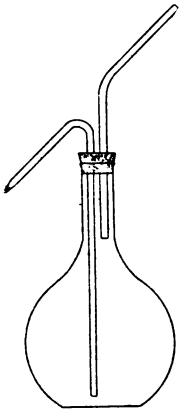
| | Per cent. |
|---|---|
| Silica ... ... ... ... ... ... | 5·10 |
| Alumina ... ... ... ... ... ... | 3·42 |
| Carbonate of lime... ... ... ... | 1·20 |
| Undetermined ... ... ... ... ... | ·18 |
| | 9·90 |

and the proportion of lime in the analysis of a cement will vary in the following proportions. If in the raw material mixing the percentage of carbonate of lime be 76, and this material be burned in an intermittent kiln with eight cwt. of the above coke per ton of clinker, the resultant cement would contain a percentage of lime equal to 61·73. But if, on the other hand, the same raw material is burned in a continuous kiln where three cwt. of coke per ton of clinker only is required, the analysis of cement would show the percentage of lime to be 63·15.

An analysis of cement is conducted as follows:—

Half a gramme (500 milligrammes) of the finely-powdered sample is carefully weighed in a platinum crucible and ignited, at first over a bunsen gas burner and afterwards over a good blast lamp. It is then cooled in a dry atmosphere and weighed again. The loss of weight equals moisture and carbonic anhydride.

*Silica.*—The same sample is now transferred to a large platinum dish and dissolved in hydrochloric acid and distilled water; about 5 cubic centimetres (5 c.c.) of the former and 10 c.c. of the latter. The solution is evaporated to dryness on a steam bath, moistened with dilute hydrochloric acid, and again evaporated to complete dryness. This operation may, with advantage, be repeated several times, to ensure that the silica, which separates from the acid solution of the cement, has become thoroughly dry, otherwise a portion of it would redissolve on a further portion of acid being added. The dry residue in the platinum dish is now digested on the steam bath with 10 c.c. of hydrochloric acid and 30 c.c. of distilled water until all is dissolved with the exception of a perfectly white powder which consists of silica. The contents of the dish are now further diluted with distilled water and filtered through an ashless filter paper, 9 centimetres in diameter, taking care to remove every particle of silica from the dish by washing it into the filter with boiling water. The filter paper which now contains the whole of the silica is thoroughly washed with a spray of hot water, the filtrate and washings being collected in a conical glass beaker.

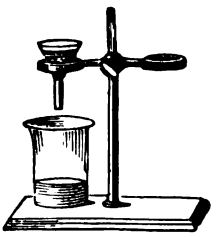


LABORATORY WASH BOTTLE.

The filter paper containing the silica is dried and ignited in a platinum crucible, at first gently, over a bunsen gas burner until the paper is all consumed, and afterwards for five minutes over a blast lamp. It is then allowed to cool in a dry atmosphere, and weighed, the weight of the empty crucible being known; the weight of silica is obtained by difference: the number of milligrammes of silica obtained ÷ 5 = percentage of silica in the sample.

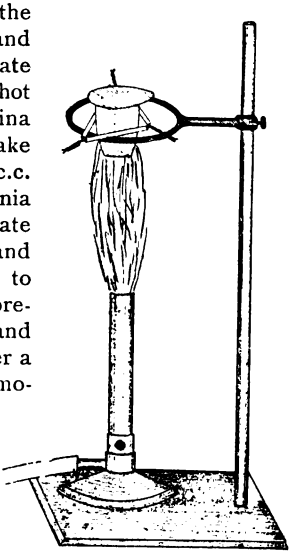
*Alumina and Oxide of Iron.*—The filtrate and washings from the silica are heated to boiling in the glass beaker in which they were collected, about 5 c.c. of bromine water added to ensure that the iron contained in the solution is fully oxidised, and the whole boiled until excess of bromine is dissipated. Solution of ammonia is now added in quantity sufficient to neutralise the hydrochloric acid present and until a distinct smell of ammonia is observed in the liquid after being stirred with a glass rod. The solution is then boiled gently until the

smell of ammonia has nearly disappeared. At this stage a reddish-brown, gelatinous precipitate will be observed in the liquid. This consists of alumina and oxide of iron, and, whilst the liquid is still hot, must be filtered off on a filter paper similar to the one used for the silica. The whole of the liquid should be passed through the filter, and the beaker in which the precipitation was made washed out with a spray of hot water (using distilled water) from a wash bottle. The filter paper and precipitate must then be washed, the filtrate and washings being collected in a large conical glass beaker, always taking care that none is lost.



FILTRATION.

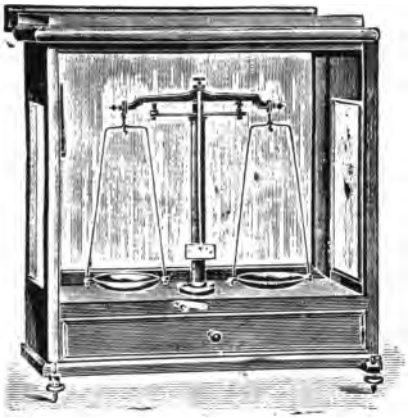
The precipitate of alumina and oxide of iron is now redissolved in dilute hydrochloric acid (one part of acid to 10 of water) by passing about 10 c.c. of the dilute acid through the filter and collecting the filtrate in a separate beaker. Wash the filter with hot water so that no trace of the alumina and oxide of iron is lost and make up the solution to about 50 c.c. Precipitate again by adding ammonia as before, and collect the precipitate on a fresh filter paper. Wash and add the filtrate and washings to those obtained from the first precipitation. Dry the precipitate and ignite in a platinum crucible over a bunsen gas burner, cool in a dry atmosphere and weigh : the weight in milligrammes ÷ 5 = percentage of alumina and oxide of iron in the sample. The object of the double precipitation is to free the precipitate from all traces of lime which would otherwise contaminate the precipitate and cause a slight error in the analysis.



FOR DRYING, IGNITION, AND FUSING.

*Lime.*—The filtrate and washings from the last operation now contain the whole of the lime which is removed by precipitation with oxalate of ammonia. The liquid is boiled

and a saturated solution of oxalate of ammonia is added until the whole of the lime is precipitated as oxalate of lime, that is until no more white precipitate is produced on the addition of a further quantity of the oxalate of ammonia. The beaker is covered with paper and kept in a hot place (but not boiling) until the precipitate has settled down and left the liquid quite clear. It is then filtered and washed with hot water with the same precautions observed in the previous operations. The precipitate is burnt in the platinum crucible, at first very slowly over a low flame from the bunsen burner and afterwards at the highest temperature of the blast lamp, until the weight

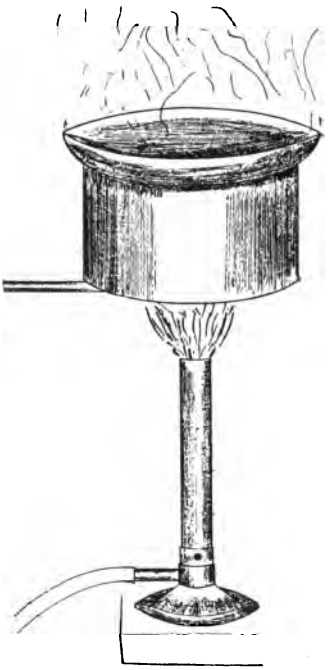


CHEMICAL BALANCE.

is constant and ceases to lose any more by further ignition: the weight in milligrammes ÷ 5 = percentage of lime in the sample.

*Magnesia.*—The filtrate and washings from the last operation, which will now amount to a considerable bulk, must be reduced by evaporation before the analysis can be proceeded with. For this purpose place the liquid in a large porcelain evaporating dish and boil gently until it is reduced to a bulk of about 40 c.c. If the liquid now is not quite clear, filter it, washing the evaporating dish and filter paper with a little water; cool the liquid by standing the beaker in cold water, add about 10 c.c. of a 10 per cent. solution of phosphate of soda and stir well with a glass rod, being careful to avoid rubbing the rod against the sides of the beaker. Now make

the solution strongly ammoniacal by the addition of about 15 c.c. of the strongest liquid ammonia, cover the beaker with paper and stand it in a cool place for at least four hours. During that time a crystalline precipitate of the double phosphate of magnesia and ammonia will have formed; filter and wash with a dilute solution of ammonia (10 per cent. of strong ammonia in distilled water), being careful to wash all crystals from the sides and bottom of the beaker; dry the filter and precipitate, and ignite, at first very gently and afterwards at the highest temperature of the blast lamp. The precipitate will now consist of pyrophosphate of magnesia and must be weighed in that state after the usual precautions of cooling in a dry atmosphere, after which the amount of magnesia contained in it can be arrived at by calculation. As 222 parts of pyrophosphate of magnesia contain 80 parts of magnesia, if the weight obtained be multiplied by the factor ·36036, the product will equal the weight of magnesia contained in the 500 milligrammes of cement taken for analysis, and this number divided by 5 will give the percentage of magnesia.



LABORATORY APPARATUS FOR EVAPORATION.

*Sulphuric Anhydride.*—For the estimation of sulphuric anhydride, a fresh portion of the finely-ground cement must be taken. Weigh one gramme of the sample and dissolve it in 10 per cent. solution of hydrochloric acid in a glass beaker; boil gently, and if not quite clear, filter it and wash the filter paper with hot water. Bring the filtrate to a boil, and precipitate the sulphuric anhydride by adding a 10 per cent. solution of barium chloride until no more white precipitate is produced. This white precipitate is sulphate of barium. The

beaker must now be kept at a gentle heat, but not boiling, for some time until the precipitate settles and the liquid above it is quite clear. It must now be filtered on an ashless filter paper and well washed with hot water; burn the filter paper and precipitate, when dry, in a platinum crucible over a powerful bunsen flame; cool and weigh with the usual precautions; 233 parts of sulphate of barium contain 80 parts of sulphuric anhydride, so the weight of the precipitate obtained in milligrammes must be multiplied by the factor ·34335, and the product divided by 10 will give the percentage of sulphuric anhydride in the sample.

The analysis is now complete with the exception of alkalies and loss, which are usually estimated by difference; that is, the difference between the sum of the various substances estimated above and 100 parts.

The dry atmosphere referred to as necessary for the cooling of the crucible and contents after ignition and before weighing is best obtained by placing a jar or open wide-mouth bottle of strong sulphuric acid under a glass bell jar. The acid will absorb all moisture from the atmosphere contained in the jar. The crucible can be placed under the jar to cool near the sulphuric acid.

It is often desired by cement users to estimate the amount of lime only in a sample of cement, and as this is a simple operation we may include the process under this heading. Take one gramme of the cement and treat it in a conical beaker with a small quantity of concentrated hydrochloric acid. A few drops of nitric acid are added and the contents evaporated to dryness and heated till the residue is of a distinctly red colour. Then re-dissolve this residue with diluted hydrochloric acid and the lime is precipitated by adding an excess of ammonium oxalate.

The silica, alumina, and iron are filtered off and the precipitated calcium as oxalate is ignited to form CaO (lime) as described above.

## VIII.—Test for Weight and Specific Gravity.

THE present period of the fine grinding of cement has rendered useless and made obsolete the old time test of "weight per bushel." So long as all cements were ground to about the same degree of fineness—a degree which, by the way, was not to be compared with the fineness of cement now put on the market—the requirement that a cement should weigh a specified number of pounds per striked bushel was found fairly satisfactory when made workable by uniform methods in carrying out the test. In many specifications even now one may find it stipulated that the cement shall weigh "not less than 112 lbs. per striked bushel," and qualifying details of the test are added as to the way in which the measure shall be filled, viz., from a hopper about 18 inches above.

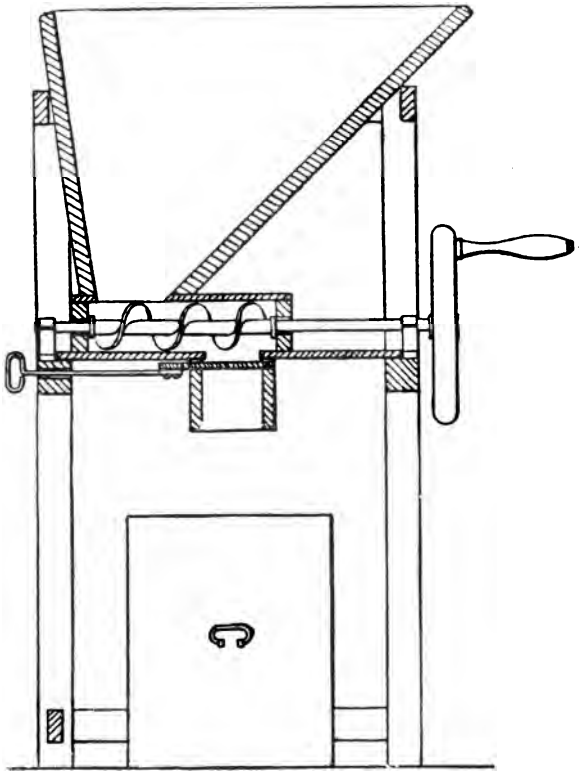
The weight of cement per bushel was a test first used in the series of cement tests, and this was doubtless to ensure the material being of a well-burned and unadulterated quality, and was in vogue when what was presumed to be a heavy cement was more in favour than a light cement, without regard to the fineness; but its continued use to-day would only be of value if the bushel test were of a graduated scale according to the fineness of the grinding, for the finer a cement is ground the more bulky it is and the less is its weight per bushel.

As the demand for finer cement increases, the weight of 112 to 120 lbs. per bushel, once easily attained, cannot now be reached, and the weight of a well-burned cement ground fine enough to pass through a sieve having 5,776 meshes to the square inch (76 × 76) will be about 104 to 108 lbs.

Two methods of determining the weight of cement per bushel are those as illustrated here, and consist of apparatus so arranged that the hoppers have no direct communication with the bushel measure. The cement thus falls into the measure at a uniform rate and to an equal density, affording comparative determinations between the weights of different brands of cement.

The weight of cement is now, however, more scientifically

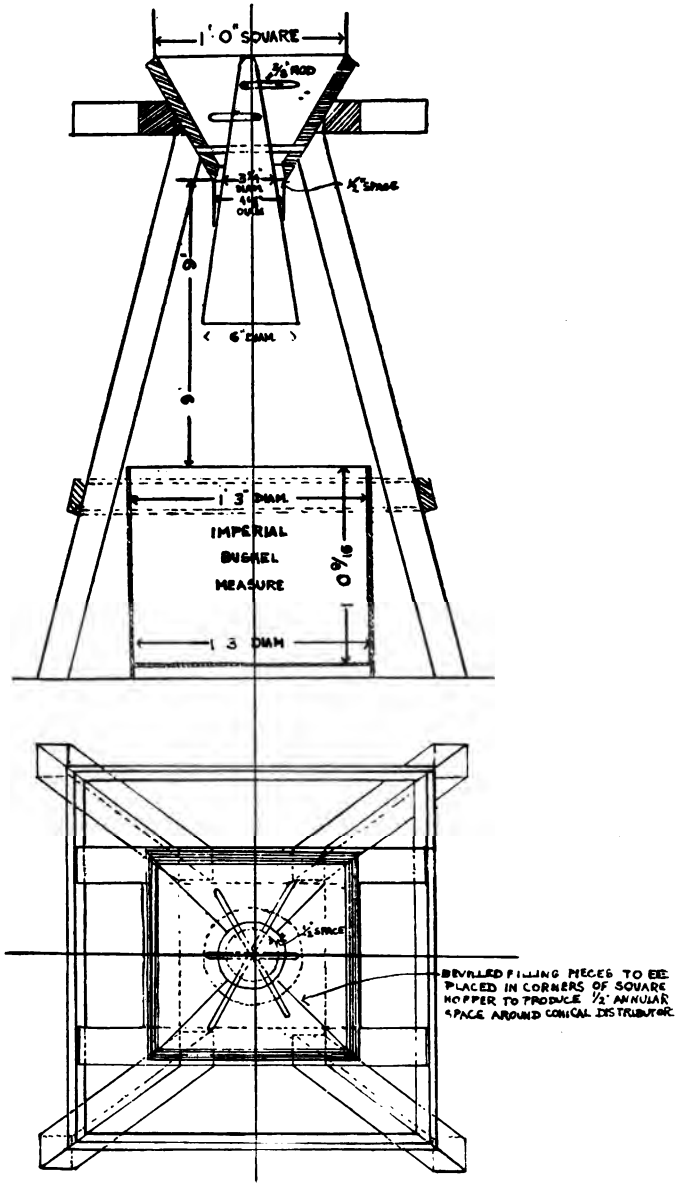
ascertained by calculating its Specific Gravity, or the weight of cement as compared with the weight of an equal volume of water or other standard substance at the same temperature and pressure. This test is carried out with facility by one or



HOPPER FOR THE WEIGHT PER BUSHEL TEST.

other of the simple appliances which have been devised, and the results are immediately known.

The specific gravity of Portland cement which has not been calcined at a sufficiently high temperature, or which contains a considerable portion of free lime, varies from 2·9 to 3·05, and a good cement when freshly ground usually has a specific gravity of 3·15. The age of the cement to be tested must first be taken into account in appreciating the value of this test, the




HOPPER AND BUSHEL MEASURE FOR ASCERTAINING WEIGHT OF PORTLAND CEMENT.

results of which are found to decrease according to the time the cement has been in store, because of its absorbing carbon dioxide and water vapour from the atmosphere. Most freshly-ground cements have a specific gravity of 3·15, and an aerated cement can be brought back to its original condition by heating to redness for a few minutes and so drive off the moisture and carbonic acid gas absorbed since being ground.

A high specific gravity does not, however, necessarily prove a cement to be of high quality; for an adulteration may be added, such as slag, which does not reduce the specific gravity; although generally speaking the specific gravity test has a value in that other adulterations most likely to be practised, and most to be feared, are made with materials which reduce the specific gravity; and the test is also useful in determining an underburned cement which may fall below 3·00, or an over-burned product in which the specific gravity may reach 3·5. The test for specific gravity is of value when care is exercised in the ascertaining of results, and although rarely adopted as an ordinary test by cement users, yet with the accuracy of the laboratory, where the necessary appliances are at hand, a reliable result is readily obtained.

The chief causes likely to affect results, and therefore to be guarded against, are as follows:—

Incorrect weighing of the cement sample for test.

Variation of temperature during test.

Waste of cement in filling apparatus, and air bubbles.

A large number of appliances have been devised for the carrying out of the specific gravity test, and a brief description, together with illustrations of those more commonly in use in this country, is given here.

### *Mann's Gravimeter.*

This apparatus, one of the first used for the test, consists of a small glass beaker, which is to be filled with 1,000 grains of cement.

The graduated pipette held above is filled to the mark B with paraffin—this being the cheapest material which does not act on the cement—and the paraffin is then filled into the lower vessel until the contents reach the mark A.

The height of the column of liquid remaining in the pipette determines the specific gravity, which can be at once read off the stem, the size and graduations of which are specially prepared for this test.

*Keates' Specific Gravity Bottle.*

The ordinary specific gravity bottle affords as correct a result as can be wished, but necessitates a knowledge of the specific gravity of the liquid employed for the test.

Here the upper bulb of the apparatus is of known capacity (1,000 grains), and the vessel is filled with liquid (generally turpentine) to the mark A. and weighed.

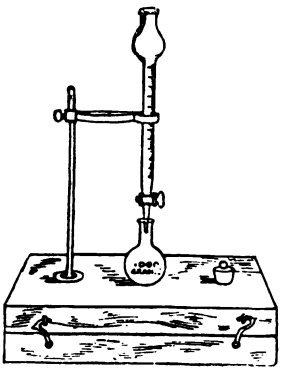
The cement is then introduced until the level of the liquid reaches B., when it is weighed again.

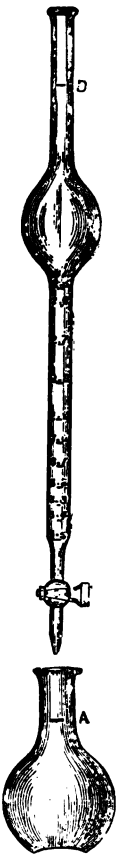
The difference of weighing is added cement, and the specific gravity is calculated thus:—

The capacity of the top bulb between marks A. and B. is 1,000 grains water measure, which equals 64·8 cubic centimètres, *i.e.*, 64·8 grammes of water.

Hence the specific gravity =

$$\frac{\text{Weight of added cement in grammes.}}{64{\cdot}8}$$






MANN'S GRAVIMETER

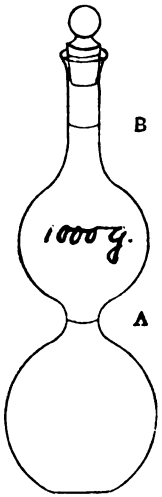
In this case the volume is fixed and the weight variable, but in the following method of test the weight is fixed and the volume variable.

*Blount's Volumenometer.*

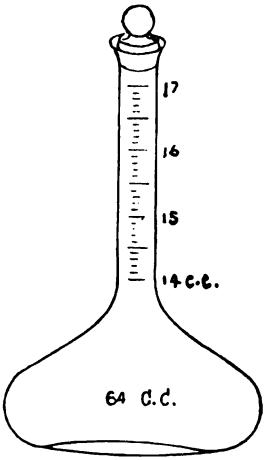
An extremely simple form of the specific gravity test is as named above, and consists of a small flask, flattened so as to

ensure its stability, and provided with a short slender neck with fine graduations. The lowest graduation mark is 14 C.C. (the reason for which will be seen presently), and the capacity of the flask up to this mark is known, and equals 64 C.C.

The instrument is used by running into it 50 C.C. of oil of turpentine from a pipette, which has been accurately calibrated against the flask. As the oil of turpentine is introduced by means of a pipette, the neck of the apparatus is kept dry. A known weight of cement (50 grains) is then




KEATES' SPECIFIC GRAVITY BOTTLE.




BLOUNT'S VOLUMENOMETER.

added through a small funnel so as not to block the tube. This cement, of course, displaces a certain volume of the liquid and raises its level in the bottle; and as all ordinary cements have a specific gravity, such that the displacement caused by 50 grains falls between 14 C.C. and 20 C.C., the former has been taken as the lowest graduation mark on the neck. Any displacement greater than 14 C.C. is therefore registered on the neck, and may be at once read off.

The specific gravity thus =

$$\frac{50 \text{ (}i.e.\text{, weight of cement).}}{\text{Volume of liquid displaced, in C.C.}}$$

(*i.e.*, reading on the neck).

The temperature of the turpentine must be known, but need

not be fixed at any standard point, and after the operation the volumenometer (which is stoppered to prevent evaporation) is brought to the same temperature by immersion in the same vessel of water as that previously used for the stock bottle of turpentine.

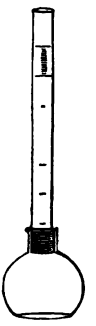
Seeing that in all cases the temperature before and after the displacement of the liquid by the cement must be identical, because of the high co-efficient of expansion of oil of turpentine and petroleum, it is evident that an apparatus of small total capacity, such as that described above, is convenient, as it can be immersed bodily in a beaker of water and brought to the proper temperature with ease and rapidity.

GRIFFIN'S SPECIFIC GRAVITY FLASK.

*Griffin's Specific Gravity Flask.*

This appliance is convenient in that a larger quantity of cement may be dealt with, and so the possibility of error experienced in using a small quantity of cement is obviated. The test is carried out by introducing 200 cubic cent. of petroleum into the dry flask, keeping the neck of the flask thoroughly dry so that the cement does not adhere when ultimately added; 150 grammes of cement are then carefully introduced.

The flask should then be stoppered and lightly shaken so as to remove any air bubbles; then allow the contents to settle in a vessel containing water of a temperature equal to the petroleum when added, and read off the cubic centimètres on the graduated stem.



SCHUMANN'S SPECIFIC GRAVITY BOTTLE.

In calculating the specific gravity, the 200 C.C. of petroleum should be deducted from the reading, and the result will give the volume occupied by 150 grammes of cement, thus: if the displacement is at 249·0 it follows that 150 grammes of cement have displaced 49 C.C. of petroleum. The displacement divided into the weight of cement (150 grammes gives the specific gravity, which in this case would be 3·061).

## IX.—Fineness.

Possibly the first enquiry into quality made by the cement user is to test the fineness of a sample of the material under notice; so in passing through the manufacturers' stores, or when the first bag is opened on the contractors' works, the cement is mechanically and half-unconsciously passed through the fingers in order to ascertain the fineness. The coarse particles in a cement can thus be readily perceived, and the practised tester is able in this way to gauge approximately the residue present in the sample.

For the past three or four years there has been a growing desire on the part of engineers for a much finer cement, and it may be said that the principle of fine grinding is now in the ascendancy—an improvement in the manufacture greatly in favour of the consumer both as regards economy in use and reliability in result. Much has already been said as to the value of fine cements, but it is necessary to further explain what results are to be expected in the testing and proper uses of a finely ground material; for unless carefully dealt with and thoroughly understood, a fine cement is calculated rather to prejudice the cement user against what is undoubtedly a superior article. Years ago the usual fineness called for in a cement was about 10 per cent. residue on a 50 × 50 sieve (*i.e.*, 2,500 meshes to the square inch) but to-day the fineness is more likely to be :—

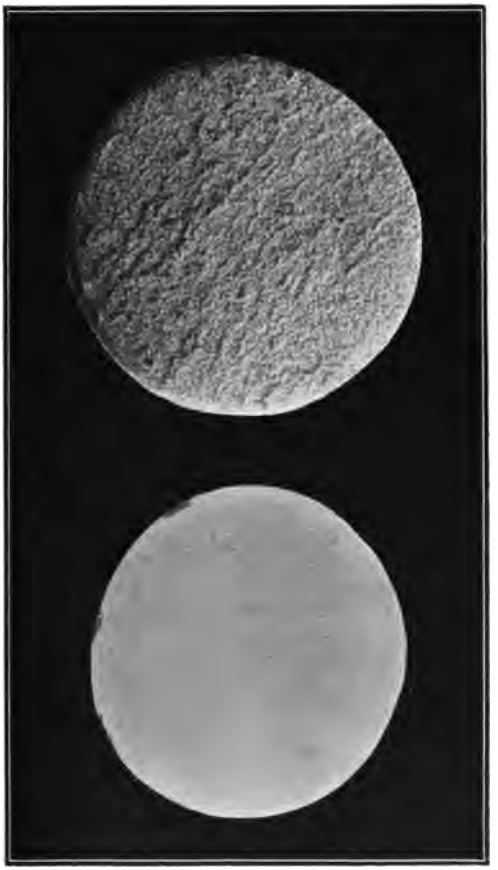
| | | | | |
|---|---|---|---|---|
| Sieve | 50 × 50 | ... ... ... ... | Residue | Nil. |
| ,, | 76 × 76 | ... ... ... ... | ,, | 2 % |
| ,, | 100 × 100 | ... ... ... ... | ,, | 5 % |
| ,, | 180 × 100 | ... ... ... ... | ,, | 14 % |

Too much attention indeed cannot be paid to fineness of grinding, for the finer the cement the more intimately can it be incorporated into the aggregate used for concrete, and therefore the stronger the work, yet on the other hand the more must the properties of a fine cement be studied.

The test for fineness derives importance from the fact, apparently well established, that, other qualities being equal, the fine cement has a much greater sand or aggregate carrying

capacity; that is, it will show an increased strength with the same charge of sand, or equal strength with a greater charge.

Portland cement, as delivered by the manufacturer, consists of a mixture of coarse and fine particles, respectively



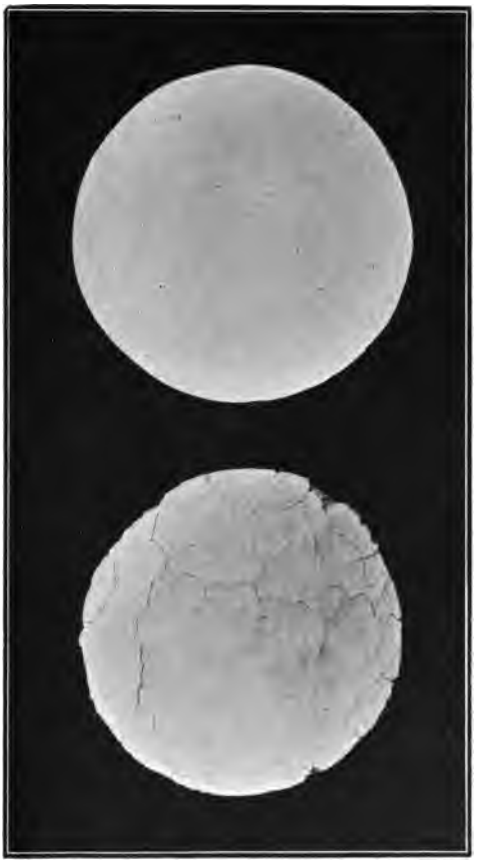

known as "residue" and "flour," and the value of a "floury" cement consists in this: First, that the cementitious property of the material is believed to reside principally, if not wholly, in the very fine particles; and, secondly, that the "residue" consists of a practically inert material, or even possibly so

much adulteration. This residue—when not an adulteration—is found to be a cement (generally the hardest and best-burned material) that has been reduced, in the process of grinding, only sufficiently fine for the water added in use to attack the surface of the particles, the interior of which remains inactive. If these were reduced to flour, it would be found to be a good quality cement, showing a high tensile resistance.

A good brand of Portland cement, as ground at the present time, should contain about 50 per cent. of impalpable flour. It has been stated, then, that the flour of a cement is alone the active agency, and full-size photos are here given of test pats of the residue and flour of which a Portland cement is composed.

The chief advantages resulting from the fine grinding of cement may be stated as follows:—(1) A fine cement is used with greater safety in work. This is confirmed by the fact that the material is nearly always able to withstand the hot tests for soundness, and this again is due to the fact that the atmospheric moisture—or even the water used in gauging—at once attacks any free lime, and thus renders ultimate disintegration practically impossible. A photo is here given of a coarsely ground cement (15 per cent. residue, 76 by 76 sieve) which has been subjected to a steam test, and may be compared with a test pat of the same brand of cement when re-ground so as to pass through a 76 by 76 sieve with 1 per cent. residue. It will be noticed that the coarse sample shows a serious disintegration, whereas the finely ground sample has withstood the same test without showing any sign of unsoundness. (2) The fine grinding of a cement renders the material of a quick setting nature (this, however, should not be confounded with what is ignorantly termed "hot" cement), the cause of this quick hardening being that the water used in gauging acts more readily on the soluble portions of the material now laid bare by the finer grinding. It must be noted, however, that finely ground cements have a common tendency to develop contraction cracks when made up into test pats unless special precautions are adopted to prevent them; because the cement has been deprived of a large amount of the tensile resistance of a coarser material and is therefore much more sensitive to the hygrometric conditions of the air. To illustrate this point further, three photos are here given of test pats of a finely ground cement containing 2 per cent. residue on a 76 by 76 mesh sieve and

53 per cent. of flour. Plate 1 shows the neat cement pat which, when gauged, was enclosed in a damp box to set, and is thus thoroughly sound. Plate 2 shows another pat of the same cement placed in the air to dry and which has developed



A Coarse Cement subjected to Steam Test. The Same Cement Re-ground and subjected to Steam Test.

some contraction cracks. Plate 3 is a quite sound test pat made up of a mixture of the same cement and sand in the proportions of one and one and treated under the same conditions as the unsound pat in Plate 2. (3) Fine cement is found to develop its tensile strength in much shorter periods

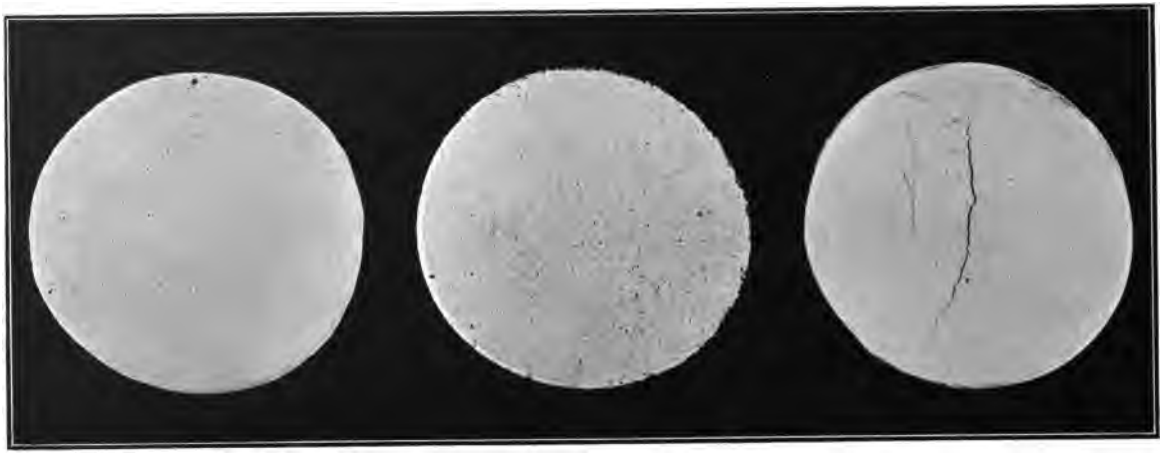


PLATE 1. PLATE 3. PLATE 2.

than a coarsely ground product, and thus there will only be slight differences between the three and seven days tests. This is the result of the active particles being the more readily and immediately attacked after the gauging of the briquettes.

It is of extreme importance in considering these experiments to bear in mind that they do not record the results due to any one brand of cement, but that samples of the best brands now upon the market were treated in order that reliable data upon the point at issue—viz., fineness of grinding—might be arrived at. Where the using of a neat cement for any detail of construction work is adopted, the same results as would be obtained with a coarsely ground material must not be expected from a modern finely ground product; and since a good proportion of residue is now done away with in first class cements, a mixture of sand may be necessary to ensure against the contraction cracks which would probably develop in a fine cement used neat.

The possibilities of economy and increased efficiency in the direction here indicated, are by no means sufficiently appreciated at the present time by cement users, even if, indeed, they are observed at all; and we are not overstating the case when we say that by using a finely ground cement with a judicious admixture of sand, the contractor's work can be carried out far more satisfactorily, and at about half the cost, as compared either with that executed in former times by employing the proportions of aggregate in use with the coarser cements then supplied; or with that often done nowadays by using a fine cement neat.

It has been shown, then, that the proportion of flour and residue contained in a cement is a point of material importance; and after the percentage of each has been ascertained in a given sample an intelligent as well as an economical use of the material should follow from a knowledge of the manufacturer's increased expense in production and the reduction of the works' output in supplying a finely ground product.

The value of a good quality modern cement (A) containing 58 per cent. of "flour" may be here demonstrated by comparing the result of its tensile strength tests with those of other well-known brands of English cement (B) but more coarsely ground.

Thus, from what has been stated above, it will be seen that the test for fineness should be directed to determining the

proportion which is very fine rather than the residue above a certain size.

A paper recently read before the Society of Engineers suggested that in the interests of uniform testing for fineness by sieving, the diameter of wire should be brought into line with

A.

| Fineness. | Flour. | 3 Sand to 1 Cement. 1″ × 1″ section. | | |
|---|---|---|---|---|
| | | 7 days. | 14 days. | 28 days. |
| 5% 100² | 58% | 310 lbs. | 320 lbs. | 370 lbs. |
| | | 310 ,, | 320 ,, | 360 ,, |
| ½% 76² | ,, | 300 ,, | 310 ,, | 350 ,, |
| | | 300 ,, | 310 ,, | 350 ,, |
| Nil 52² | ,, | 290 ,, | 300 ,, | 340 ,, |
| | | 290 ,, | 280 ,, | 300 ,, |
| Average... ... ... | | 300 lbs. | 306⅔ lbs. | 345 lbs. |

B.

| Fineness. | 3 Sand to 1 Cement. 1″ × 1″ section. | |
|---|---|---|
| | 7 days. | 28 days. |
| 4% 50² | 187 lbs. | 245 lbs. |
| 8% ,, | 183 ,, | 276 ,, |
| 2·5% ,, | 240 ,, | 297 ,, |
| Average ... ... | 203⅓ lbs. | 272⅔ lbs. |

the Continental and American standard, which is, that the thickness of the wire shall be one-half the size of the opening (see Table, p. 71).

The sieves should be frequently examined—under a magnifying glass if possible—to see that no wires are displaced, leaving apertures larger than the normal.

The sample of cement for sieving is dried at a temperature of about 120° F.; a quantity weighing 100 grams is perhaps the most convenient. The weight in grams of the residue then remaining on the sieve represents the percentage retained by that particular sieve. A convenient size sieve for this test is

| No. of Sieve. | New Standard Wire Gauge. | Thickness of of Wire. | Width of Opening. |
|---|---|---|---|
| 50 × 50 | 37 | ·0068 | ·0132 |
| 76 × 76 | 41 | ·0044 | ·0087 |
| 80 × 80 | 41½ | ·0042 | ·0083 |
| 100 × 100 | 44 | ·0032 | ·0067 |
| 180 × 180 | 47½ | ·0018 | ·0037 |

about 8 inches in diameter. The manner in which the shaking is carried out determines the length of time required for the operation; some five minutes' gentle and continuous tapping of the sieve on a table should, however, be found ample.

CEMENT TESTING SIEVE.

The system of determining the fineness of Portland cement by the percentage of residue on a certain sieve has been subjected to much enquiry and argument, chiefly on account of the variations found in the thickness of the wire of which the gauge of the sieving is manufactured. In this country there appears to be no general standard of size for the wire, nor is there any agreement as to how long the actual sieving process is to be continued. In some cases, however, the specification to which a cement has to be supplied gives these data. The importance of the thickness of the wire used in sieve making is obvious when the difference is observed in the results of tests for fineness by two sieves of the same

number of meshes per square inch, but which differ materially in the size of the wire; the reason, of course, being that the apertures are much smaller in one case than in the other. The diameters of the sieving used in the testing of cements by the Admiralty, War Office, and India Office Department of the Government are as follows:—

| Residue per cent. | Mesh Sieve. | Wire. |
|---|---|---|
| 2 ... ... | 50 × 50 ... ... | ·007 |
| 10 ... ... | 76 × 76 ... ... | ·005 |

The testing of the fineness of a cement—and this should be performed by using the finest sieve procurable—can be carried out with facility and rapidity. A mechanical sifter is used in America which works automatically by a jig motion, and thus eliminates personal error in the fineness test. And again, a percentage scale is found useful for this test. The scale consists of a beam balance, with graduations from 0 to 100 per cent., and the amount of residue can be at once read off, after adjusting the poise on the beam until the scale balances.

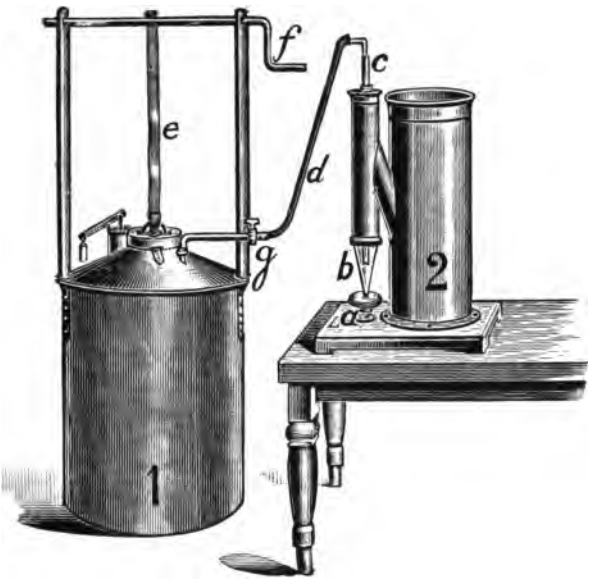
Since, however, it is desirable to know the percentage of actual flour in a given sample according to the different classes of grinding machines used in the process of manufacture, an apparatus has recently been devised for this purpose, and is illustrated here. Although this is a tedious and lengthy operation, lasting some thirty to forty-five minutes, its results are interesting, and with some improvement the test by the flourometer—as the apparatus for the testing of flour is termed—will no doubt be more generally adopted than is at present the case. The flourometer operates by a fixed quantity of cement being placed in a special receptacle and air forced through it, causing the cement flour to separate from the residue. When all the flour is thus extracted the residue is weighed, and the result shows what proportion of flour was originally contained in the sample. A description of the flourometer, as well as the directions for using the same, are here given:—

The apparatus consists of an aerometer (1) for providing the requisite supply of air at any required pressure, and the flourometer itself, (2) with which the separation is effected.

The screw *a* holding up the glass *b* is slackened until, the brass tube *c* being lifted up out of the way, the glass can be removed. Into this glass a quantity (preferably 40 grammes) of cement is placed, and the glass replaced in its proper position. Taking due care that the glass is in its position on

the rubber collar, screw *a* is tightened. Should there be any appearance of leakage of the flour round the top of the glass on starting the test it may be necessary to shut off the air, slightly slacken the screw and twist the glass round, then tightening up again.

The aerometer being connected with the flourometer by the rubber tube *d*, and the former having been lifted up to fill by




THE STANDARD FLOUROMETER.

hanging the rope or leather strap *e* on to the peg and turning the crank *f*, the air cock *g* is turned on.

It will be found that according to the fineness and age of the cement, it will at first, more or less, clog round the glass, for the purpose of obviating which the brass tube is so arranged that it can be worked about to keep the cement moving until it has parted with sufficient of its flour to run without, which should be within a few minutes of starting. If the apparatus is in a room where it is wished to make as little dust as possible, a cloth, such as a duster or handkerchief may be placed over the top, and held down on to the top edge of settling chamber by a rubber band. But this is only necessary for the first few

minutes. In order to know when the flour is all extracted it is only necessary to watch the top of the settling chamber and look down into it, when it can be judged whether any more dust is being driven off, or whether the operation is complete. The residue is then taken out of the glass and weighed to find what weight has been lost in the shape of flour, and the percentage arrived at.

The glass should be brushed out well before and after testing, to ensure the test not being spoilt by admixture of cement not intended to be there. If wished to prove that the line between flour and residue is exactly touched by the apparatus, in other words to check result, and that the cement is divided at the correct point, it may be done by first lifting the bell out of the tank of the aerometer and unhooking the weight hung at the top inside it.

Replace the bell and lay on top of it loose weights to come about 1 lb. below the weight taken out. Drive off a sample of cement and examine the flour under a microscope, also testing some of it on a piece of glass with a palette knife by rubbing it, to see that it is not gritty. Now replace the proper weight and add 1 lb. loose on top. The flour with this should be tested as before and should appear gritty on the glass, while under the microscope it should now be seen to contain some residue, this being easily picked out if the microscope is sufficiently powerful.

The aerometer should not be drawn up too quickly, as, if time is not given, in lifting it up, for the air to get in the valve, the whole weight of the water will hang upon it, and the line will break.

The brass tube should rest upon the glass just at the edge of the brass filling piece, in the bottom of it but not touching it, and the points of the V's may be bent out if necessary to adjust this.

The cock on the aerometer must be closed before and during lifting or some of the cement may be drawn out of the glass, so making the test incorrect. Some of the cement will hang up during testing in the glass, but can be dislodged by tapping the glass or screws.

Should there be any flour remaining in the bottom of the glass, as shown when the residue is turned out, the residue should be returned to the glass, care being taken that some of the cleaned residue is at the bottom, and the test prolonged for a short time.

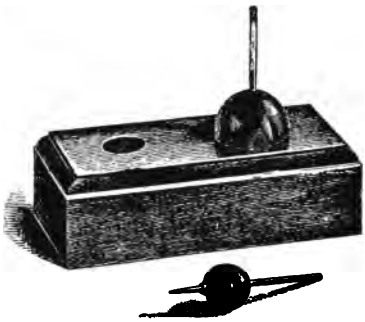
## X.—Setting.

When Portland cement is mixed with water, a plastic paste is formed which ultimately hardens into a stone-like substance; and according to the activity shown in this transition from a paste to a thoroughly hard mass, so is the material found to be of a quick or slow-setting nature. It is of importance that the cement user should be aware of the setting properties of the cement to be employed in constructional work, for unexpected results are apt to ensue from the omission of this test. It often happens that when a quick-setting material is inadvertently delivered on to the contractor's works, and is brought into use, the setting has commenced even before the mixing of the aggregate and cement is completed, with the result that this setting action being unnoticed is interfered with, and the material will not again set for some days; or, at least, until the moisture has thoroughly dried out of the mixture, and even then its cohesive value is so greatly reduced as to render the cement practically valueless. This is a common occurrence, and may be easily avoided by a systematic testing of activity. Care then should first be taken to ascertain the setting time of the cement, and next, that no greater bulk of mortar is mixed than can be used before the setting commences. Under no circumstances must a cement which has once been allowed to set be re-tempered or re-mixed for use, since from what has been said above, it will be seen that the material is thereby rendered worthless.

Cement manufacturers have it in their power to make either a quick or slow-setting cement, and unless otherwise instructed, supply the latter, which takes thirty minutes and upwards to harden on the surface. A quick-setting cement commences to harden in a few minutes, and although perhaps equally strong in its tensile resistance and constructional value, yet a cement of this nature must be used with care. It is employed only for special purposes, such as in operation under water—in plaster work, and when working in cold weather. In all other cases it is most advantageous to use a slow-setting cement.

It is generally understood that a quick-setting cement is rendered of a slower setting nature by storage, on account of the hydration of the calcium aluminate contained in it, but by this statement it should not be inferred, as it often is, that a quick-setting material is necessarily one which has not been stored, and is what is commonly termed "hot" or "fresh." These terms are undoubtedly very misleading to the average cement user. The fact of its being freshly ground has little or nothing to do with the setting properties of Portland cement; its chemical composition alone is responsible and accountable for the difference in the times of setting.

As the *strength* of a cement is known to be due to the



GILMORE NEEDLES.

effects of the calcium silicate contained in the material, so is its *activity* due to the calcium aluminate.

Portland cement usually contains between 4 and 8 per cent. alumina, and the rapidity of setting increases in proportion as the alumina rises above 6 or 8 per cent., so that a material which is shown by its chemical analysis to contain more than this amount of alumina, sets very rapidly indeed.

Many Portland cements are naturally of a quick hardening disposition, and to counteract this and to retard the setting, a form of sulphate of lime (gypsum) has to be added by the manufacturer when the cement is being ground in the stores.

The addition of gypsum is generally recognised up to about 2 per cent., and the introduction of this material is rendered necessary so as to regulate and make uniform the general setting tendencies of the cement in bulk.

For instance, a cement clinker when ground from the kilns may vary in its setting from a few minutes to some hours, and

such a material to a consumer would prove exceedingly irksome and inefficient, but by the introduction of the gypsum which is mixed with the material whilst passing through the grinding machinery, a cement is obtained which can be relied upon as being of a slow and generally uniform set.

The addition of gypsum on the other hand in no way interferes with the strength of the cement, and its introduction does not render careful aeration before use any the less desirable.

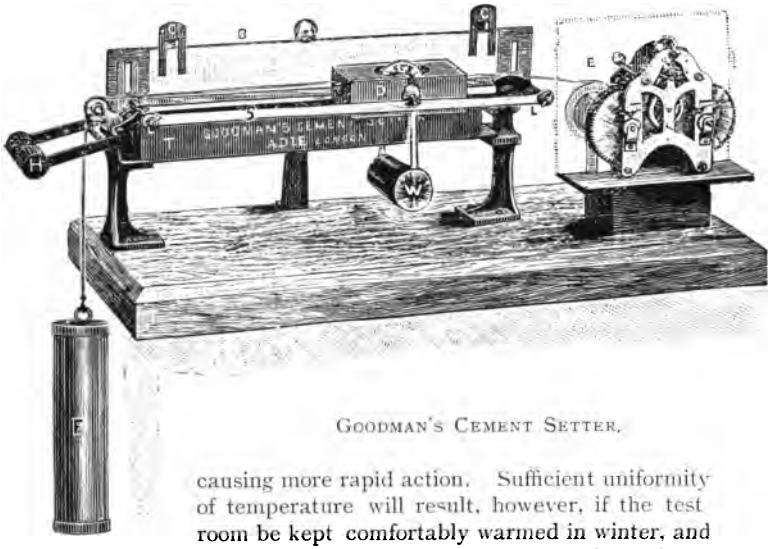
Occasionally, cements which are slow-setting when freshly

VICAT NEEDLE.

ground, have been known to undergo conversion to quick-setting on storage, and then either retain that character or revert to the original state. This is due to one of two things: (i) the high percentages of alumina (especially when the cement is prepared by the dry process of manufacture), which necessitates the addition of gypsum. This is soluble, and retards the setting of the cement, but only for a time, for when the sulphate of lime enters into combination with the calcium aluminate its restraining action is removed and the cement becomes quick-setting; (ii) the calcium oxide which is

invariably present in freshly-burned cement clinker, but which may be gradually converted into carbonate on storage. When this is the case, the cement is found to set more quickly after storing than when freshly ground.

There are some strict conditions which must be observed in testing the activity of cements. One of these is referred to more particularly in the preceding article bearing on the results of fine grinding, which more often converts into a cement of quick action what would otherwise be a slow-setting material. Again, the temperature of the test-room has a serious influence on the speed of setting—a high temperature




GOODMAN'S CEMENT SETTER.

causing more rapid action. Sufficient uniformity of temperature will result, however, if the test room be kept comfortably warmed in winter, and in summer if the specimens be kept until set under a damp cloth out of the sun in a cool room.

Generally speaking, also both the initial and final periods of setting are prolonged by the increase of water in mixing.

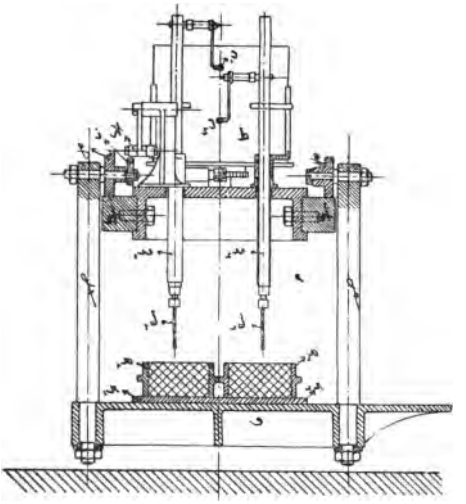
The test for activity is easily carried out with simple appliances, and its results are known in a few hours at most. Variable results from the test are caused by different local conditions of moisture and temperature, and by the different judgment of observers.

Some manufacturers claim that their cements show better results when gauged with particular percentages of water,

but it is not considered good policy to encourage these peculiarities at the expense of the uniformity of tests which is so greatly desired.

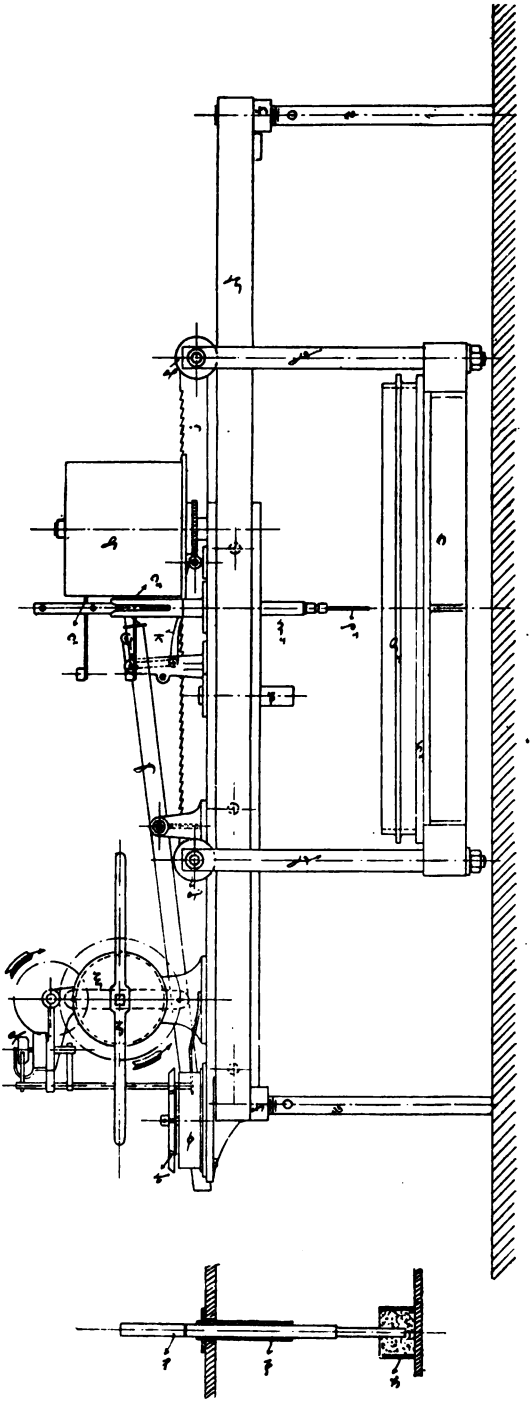
By means of a microscope and with a power of about 200 it is possible to watch cement in the process of setting, and for this purpose a little cement should be dusted on to the slide and fastened down by a coverglass, and both placed under water.

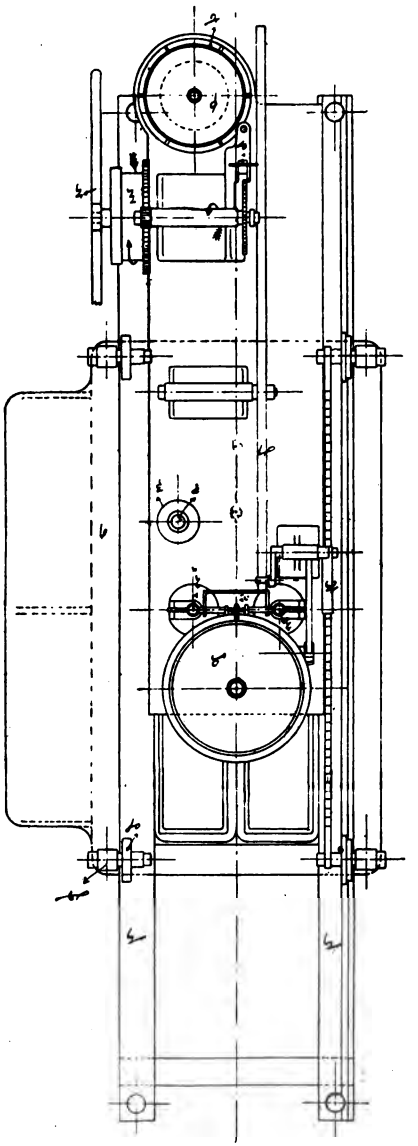
It will then be found that the grains of cement become covered with crystals, which make their appearance sometimes



in from ten to twenty minutes, or some from ten to fifteen hours, according to the activity of the sample. These crystals are the result of the solution, in the water, of a portion of the cement, and their growth and interlocking on adjoining grains unite the whole into a solid mass, and thus constitute the setting properties of cement. It will be seen that when once the crystals have formed they cannot be again dissolved; hence the worthlessness of a cement which has been re-mixed after the setting has taken place.

The test of the setting of cements has much practical importance. It is *direct* so far as its limits relate to the time necessary to get the cement in place after mixing, which must not be longer than the time of permanent set. It is *indirect*





in so far as its limits relate to the probable final strength, elasticity, and hardness of the cement mixture.

Perhaps the best apparatus for the test of setting are the Vicat and Gilmore needles, and tests for consistency are arranged with the same appliances. The Vicat needle is illustrated here and is used as follows:—

The cylindrical rubber mould is filled with about 14 ounces of neat cement mixed with water to a stiff plastic consistency. The mould is ten centimetres in diameter, and four in height, and rests on the glass plate forming part of the apparatus. It will be noticed that the machine is supplied with a plunger one centimetre in diameter and a needle with a diameter of one millimetre, each being provided with a brass disc which fits on the top of the piston; the lighter being used with the plunger. In some forms of the machine the disc which is used with the plunger remains permanently upon the piston, a light disc being placed upon this when the needle is to be used.

The face of the apparatus bears a scale graduated in millimetres and fractions of an inch, a double pointer being carried by the piston, indicating on the scale the depth of penetration. After the mould is filled with the cement mortar it is placed into position as shown in the illustration, and the plunger is allowed to sink into the cement by the weight of the disc. If the plunger penetrates to a point of six millimetres from the bottom the mortar is of the proper consistency.

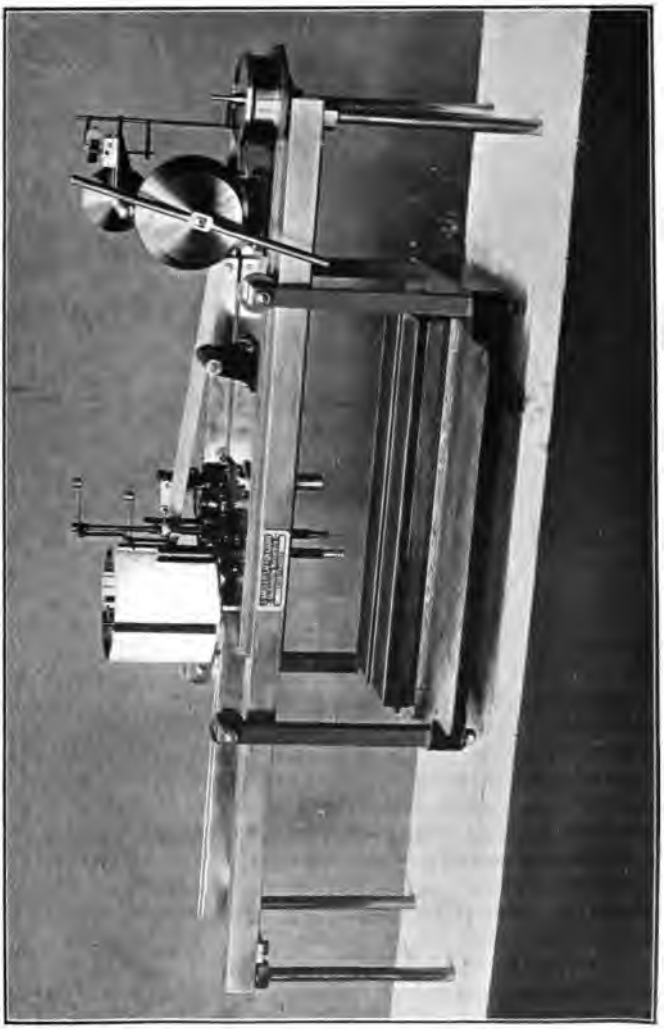
The needle is then substituted for the plunger. The time when the needle first refuses to sink entirely through the mortar is observed and noted as the beginning of the set (or initial set), and when the needle first rests upon the cement without penetrating, this is the moment of final setting.

The other test for activity is by the use of the Gilmore needles or test wires. These consist of a steel needle one-twelfth of an inch in diameter, loaded with a weight of four ounces; and another, one twenty-fourth of an inch in diameter, with a weight of sixteen ounces. When using, these needles are held lightly in a vertical position between the fingers, the point resting upon the sample.

The moment when the coarse needle fails to sink into the cement is called the time of initial set; when the fine needle will no longer penetrate, the moment of final setting.

An apparatus has been devised under the name of "Goodman's Cement Setter," by which the time and rate of

setting of cements and mortars is autographically recorded. Although a very ingenious arrangement, this method of the



"AMSLER-LAFFON" APPARATUS FOR MEASUREMENT OF CONSISTENCY.

testing of cement for setting properties appears to have been little adopted.

An illustration of the device is here given, and the working instructions are as follows:—

Wind up both barrels of the clock. See that all the working parts, especially the compensating levers L L, are well lubricated and are working freely.

Attach a piece of stiff white paper or smooth thin cardboard to the recording board B by means of the clips C C, bring the side bars S to their topmost position and run the carriage D along to make the pencil draw the upper line of the diagram.

Remove the weight W and carriage D, lift out the trough S, and *thoroughly grease* it before putting in the cement. Smooth the cement off flush with a trowel to the top of the trough, and wipe off all superfluous cement.

Replace the trough and the carriage, putting the latter at the clock end of the trough, wind up the string by turning the drum E, hang on the weight F. Oil the disc G all over and replace in the carriage, hang on the weight W and lower the disc into the cement by lifting the balance weight H; adjust the pencil spring and allow the setter to run undisturbed.

The carriage and disc travel at the rate of one inch per hour, hence the horizontal distance the pencil has travelled before it reaches the upper line of the diagram is the length of time in hours the cement has taken to set; and the slope of the curve shows the rate of setting at each instant.

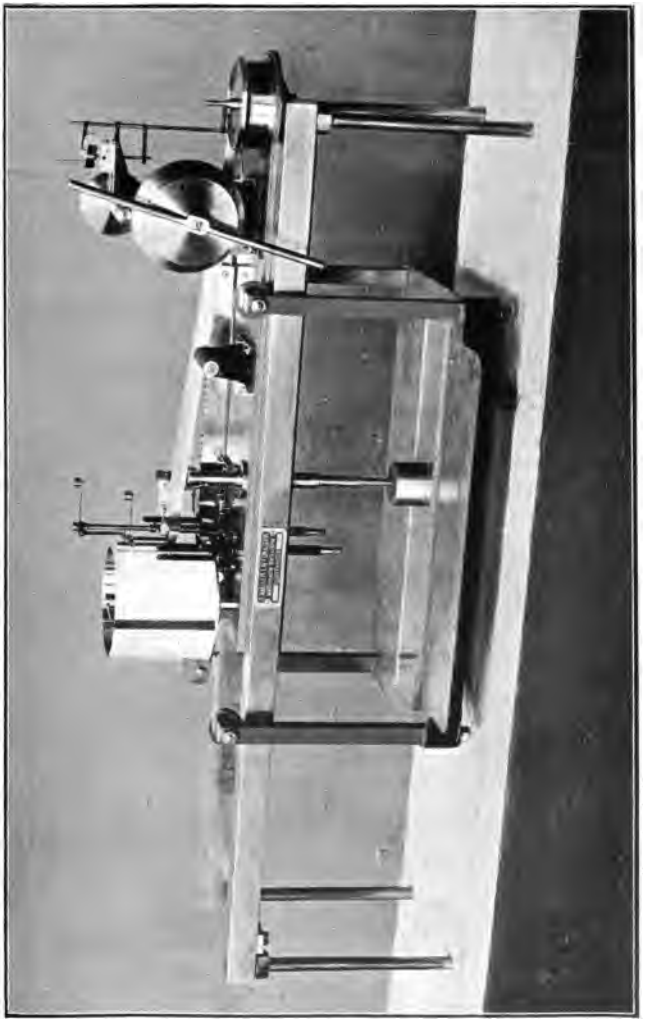
Full particulars, such as the percentage of water used in gauging, the temperature of the air, the hygrometric state of the atmosphere, should be noted on each diagram.

Another similar apparatus has been introduced on to the market more recently, and is named the "Amsler-Laffon" Cement-Setting Recorder. In testing the activity of cements by this apparatus the two moulds $A_1$ and $A_2$ are filled with a plastic paste of the sample of cement, and the needles $B_1$ and $B_2$ are lowered upon the cement at certain intervals and penetrate more or less into the mortar according to the progress of setting. The depth to which each needle enters into the mortar is recorded on the drum D by the pencils $C_1$ and $C_2$.

After each stroke of the needles the drum turns a little, and the table on which the moulds rest advances a step from the right to the left.

The needle holders are lowered and raised by the lever L, which is set in motion by a spiral spring contained in the box M. The motion is set by the clock O which lets loose the wing governor Q, and stops it again when the stroke of the lever L is completed. The disc P, with a certain number of

notches, is placed on the top of the clock and performs one turn in an hour. This determines the lapse of time between



"AMSLER-LAFFON" CEMENT-SETTING RECORDER.

two consecutive records. By changing the disc different intervals of time may be obtained. The exchange can be

carried out during the experiment without disturbing the result, and there are four discs corresponding to 5, 10, 20 and 30 minutes.

When the moulds have travelled from one end to the other, after about fifty strokes of the needles, the carriage must be pushed back by hand into the initial position and the moulds moved sideways. The diameter of the needles is one millimetre, the weight of each needle holder is 300 grammes. The spring motor is, however, sufficiently powerful to overcome heavier weights, so that the holders may be made heavier if desired.

The pin V, one centimetre in diameter and 400 grammes in weight, is used for ascertaining the right consistency of the mortar before setting. If the mixture of cement and water is correct the pin ought to stick in the mortar at about one centimetre before reaching the bottom of the mould.

A more common form of the testing for setting is that by which the thumb-nail is used on a pat of cement, and noting the times of resistance to pressure thus: A small sample of cement is made up with 25 per cent. of pure fresh water at normal temperature and formed on a piece of glass into a circular pat of about three inches in diameter, with thin edges, by about one-quarter inch thick. The initial and final setting times can then be readily ascertained by the impressions of the nail at varying intervals.

## XI.—Tensile Strength.

THE constructional value of a cement depends upon its power of setting into a rigid mass soon after it is gauged, and on its power of attaining a considerable strength in course of time. The testing of the strength of Portland cement may be performed by compressive or by tensile tests, the latter including the transverse test made by breaking a beam of the cement.

In actual work the strain to which cement is subjected is not necessarily a purely tensile or purely compressive strain owing to unequal bearings and loadings, but is more often a transverse strain. The transverse and compressive tests are, however, now rarely made, the most usual test for cement, largely for the sake of convenience, being that of its tensile strength.

The compressive stress for testing Portland cement can be readily applied by apparatus designed to this end; but the test serves no useful purpose since the compressive strength of cement is found to be in fairly constant ratio of about 10 to 1 as compared with the tensile strength, the test for which may be applied more easily and by simpler and more familiar apparatus.

At the present time the section of a cement report which receives the most attention is that dealing with the tensile strength. This, perhaps, is not surprising, when we remember that this test, although possibly the most illogical and erratic, is the most convenient.

The object of the tensile (or stretching) test is to determine the greatest stress per square inch which, under given conditions, the cement can be made to stand without rupture. If the conditions have been carefully observed, and yet several discrepant results are obtained, the highest *may* be right, but the others are certainly wrong. No averaging should be done.

In respect of the uncertainties due to the personal characteristics of the tester, and to the influence of local conditions, this test offers greater scope for error than any of the others considered.

The most scrupulous care must be observed in the manipulation, and the tester should possess natural aptitude for such work.

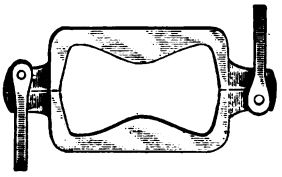
There is, unfortunately, no standard method of testing cements in this country, and engineers frequently draw up their own specifications for testing, but the average requirement for a tensile test of neat cement is from 450 to 550 lbs. per square inch in seven days, and 700 to 850 lbs. in twenty-eight days, these being the two periods most generally adopted, and, on the whole, the most convenient. A tensile strength above the average mentioned need not, however, excite suspicion as to the soundness of the product, as is often the case, for a carefully made cement will often sustain very high strains before fracture; and if such a cement withstands the far stricter accelerated tests (which will be referred to in the following article) for deciding as to the safety of the material, a high strength may certainly be looked for as one of its decided qualities.

It is, however, sometimes the case that a high tensile strength may be caused by overliming the raw material, but since a number of tests are in vogue for indisputably discovering such a weakness in a cement, one can by these means readily confirm the records of the tensile test and prove the soundness of the materials. With the now increasing demand for a finely ground cement, it is to be expected, and in fact it should be urged, that in place of neat tests an admixture of sand should be employed in estimating the value of the sample. In the neat tensile test the full value of the cement as a concreting material or as a cementing power never comes into play; and, granted that a finer cement is a more valuable product, a coarse sample will, in a neat test, give results as to tensile strength equal to those obtained by a fine cement. But on the other hand the difference between the constructive values of a coarse and a fine cement will be most noticeable in a test for tensile strength, carried out with a mixture of sand and cement in the proportion of 3 to 1.

The value of sand in the place of neat tensile tests is more appreciated day by day, and this hardly requires an explanation since cement is rarely, if ever, used in a neat state. In neat tests the full cementing power never comes into play, but in a sand test the more practical concreting qualities of the product are ascertained as well as its value as a constructive material.

The Prussian standard rules for testing cements provide

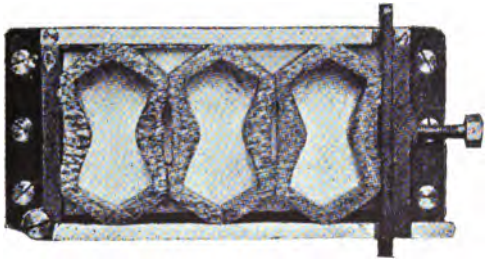
that the strength of a cement shall be always determined on a mixture of three parts by weight of quartz sand, and one part by weight of the cement, and better quality cements would be supplied and used if a similar rule were more generally adopted in this country. Where the sand tests are adopted in England the tensile strains required of a mixture in the above proportions is about 150 lbs. per square inch in



BRIQUETTE MOULD.

seven days, but this standard is too low for a finely ground product of good quality, and a strain of 200 to 250 lbs. per square inch should be demanded.

In the preparation of briquettes it is advisable, as far as possible, to have all moulds, which should be made of gun-metal, shaped exactly alike, and the gauging of each briquette should be carried out in exactly the same manner. As the



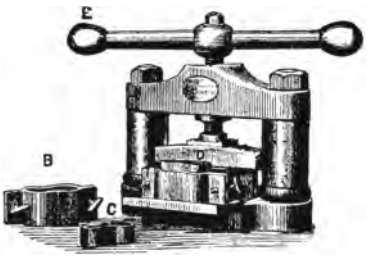
BRIQUETTE MOULD.

value of the tensile strength test depends mainly upon the preparation of the briquettes, it is necessary that precautions be taken so that the personal equation is, as far as possible, eliminated, by ensuring that the proper percentage of cement and water is always strictly observed. In preparing the briquettes, after the mixing of the sample of cement, care should be taken that the moulds have been properly cleaned and placed on small plates of iron or slate. For the neat

test weigh about five ounces of cement to eaoh briquette. Turn the weighed cement out in a heap on to the slate slab, and gradually pour on the exact amount of water which it has been previously determined will provide the consistency required.

Then trowel the cement thoroughly and quickly, and fill the mould so that the material is solid and free from air spaces, and finally trowel both sides of the briquette.

During setting the briquette should be placed in a damp place or covered with a cloth saturated with water, and allowed to remain for 24 hours in a place free from any vibration. A briquette that has thus been allowed to harden slowly, and has been kept free from any hot, dry, or draughty atmosphere, may be relied upon as being stronger, and the testing results more




"ARNOLD" PRESS.

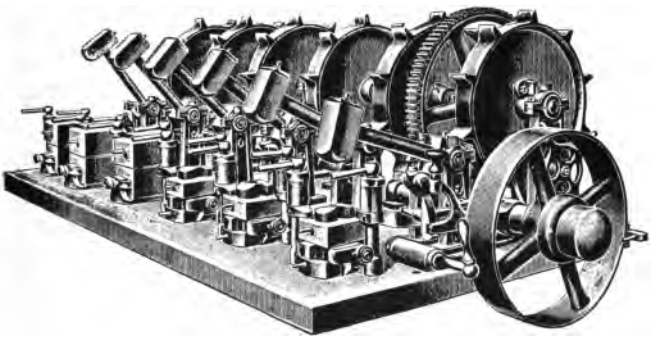
uniform than is the case where the water is evaporated from the cement too quickly.

When the briquettes are thoroughly set they should be immersed in water until ready for testing.

Another method employed by cement users for the mechanical preparation of briquettes, is that in which an Arnold's press (an illustration of which is given here) is used. The process, as seen by the writer, is as follows:—The proper quantity of cement, say 150 grammes, is evenly mixed by means of a mortar and pestle, with a small quantity of water (10 cc.) The mixed material, which in this instance is only slightly damped, is then filled into the mould (B) of exactly two inches in depth. The die (C) is the exact shape of a briquette, and is placed at the top of the cement in the mould, and the two are placed under the press (D). The screw press (E) forces the die into the mould, and the pressed briquette is thus of the desired thickness, and can be taken

from the mould at once and placed aside to set. Although a higher tensile strength can often be secured from a cement briquette prepared by a practised hand, yet a briquette made by the above process is equally fair and satisfactory. The operation, moreover, is quite easy, even to the unskilled, and a variable result in a number of briquettes of the same cement is obviated.

The "Böhmé" hammer here illustrated is universally used by the Association of German Cement Manufacturers for the moulding of cement and sand briquettes. This automatic apparatus has been little adopted in England. The "Böhmé" hammer is the standard German machine, and consists of an arrangement by which the mortar is compacted by 150 blows



"BÖHMÉ" HAMMER FOR GAUGING SIX BRIQUETTES.

of a hammer weighing two kilogrammes (4·4 lbs.) upon a plunger sliding in a guide placed upon the mould. Results of moulding briquettes by this method shows some 30 per cent. higher strains than those of hand-made briquettes.

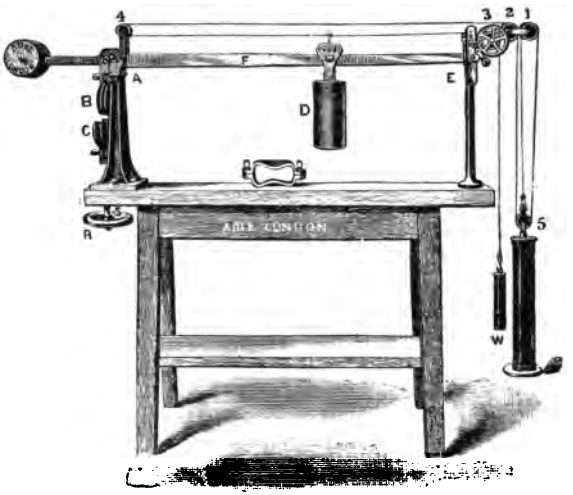
The amount of force employed in pressing the mortar into the moulds has a very marked influence on the tensile strength. Ordinarily the mortar is pressed in by hand, and it is thus impossible to estimate the intensity of the force, but in the use of the "Böhmé" hammer this is accurately calculated, and is always the same.

After the preparation of the briquettes, of which the usual shape is here shown, they should be taken from the moulds when set thoroughly hard—generally after 24 hours by hand gauging—and immersed in fresh water of 60 to 70° Fahr. until tested, and the briquettes should always be broken within one

hour of being taken from the tanks. The method of arranging the clips of the testing machine in which the briquette is held is an item needing every attention, and, in order that the stress shall be uniform, great care must be exercised in perfectly centering the briquette in the clips.

It is necessary also that the strain applied be always regular. The normal standard speed of applying the strain is 400 lbs. per minute.

The testing machines generally used in this country are




"ADIE" TESTING MACHINE.

illustrated here, the "Adie" testing machine, with the automatic regulator, being, perhaps, more often employed.

The instructions for working the "Adie" testing machine are as follows:—

Fix the forked pillar E by means of nut and washer, drop the spindle S into its place in the table, then put the standard A in position and insert the notched plate in groove of spindle, bolting down A so that the lever when strained (by putting a moulded briquette of cement into the clips B and C, and then tightening by means of the wheel R), may take its position freely in the centre of forked pillar E. Put the lever F in its place so that the knife edge rests in groove of hardened steel on top of standard A; hang on clips B and C; place head

weight in place and fix by thumb screw, and machine is then ready for use.

To test briquette, insert in the clips B and C, then turn the wheel R until the lever at E rises well above the zero line; then by turning handle on standard E, the vernier is moved gently along until the briquette breaks. The strain at which briquette has broken being then read off on lever.

With machines having two rows of figures, use the bottom row with head-weight in its place on the lever, and the top row with head-weight and thumb screw off.

The automatic regulator has been designed to give a uniform rate of travel to the vernier, so that all tests are made at an equal number of lbs. per minute, which is usually fixed at 200 lbs. per inch per minute; but this can be altered to any speed required by means of a cock in piston; it is also self-acting, and when test is started, needs no interference whatever, and directly the briquette breaks the vernier is held fast by means of clutch, or brake, until released.

To fix the automatic regulator, fasten the brass tube to floor underneath the pulley marked 2, so that the weight W just clears, and fill the tube with clear lubricating oil, attach the long cord to left-hand side of vernier, pass round pulley 4 on top of pillar A, and back and down over pulley 2, under pulley 5, and upwards round No. 1, and down again to eye at 5, attach the short cord to right-hand side of vernier, pass it over and twice round the pulley 3 to prevent slipping.

To use automatic regulator, see that vernier is at commencement of scale, then place briquette into its place, tighten by the wheel R, until the strain is sufficient to lift the lever well above the zero line on standard E, then, hang on brass weight W, which will at once commence to move vernier along the lever; see that the vernier weight does not rock while travelling. To commence another test, remove weight W, lift lever by means of lifter, which is fixed to standard E, then press on the cross handle at top of piston rod, which will let piston down gently, and return vernier to commencement of scale, and proceed as already described.

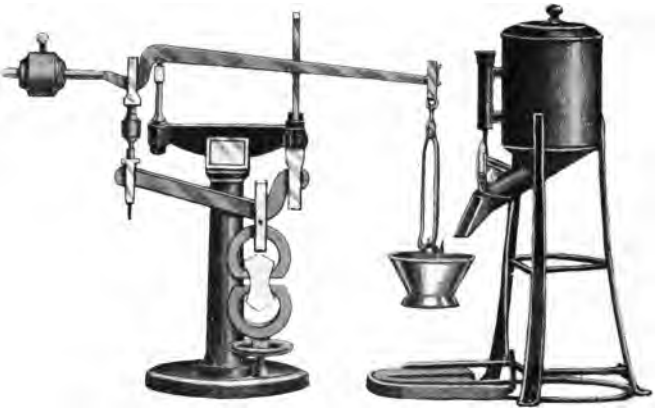
A "Michaelis" testing machine is generally used in the German cement factories, and the weight in this machine is applied by means of a stream of shot flowing into a bucket attached to the upper lever applying the rain.

Immediately the briquette breaks the bucket drops, and in doing so strikes the lever underneath, and thus automatically shuts off the stream of shot. The shot in the bucket is then

weighed upon a spring balance specially graduated, and the tensile strain reached is readily calculated.

In passing on to the testing machines used in this country, reference should be made to the "Faija" apparatus as being one commonly used by manufacturers and engineers, and a description of the working of this machine will no doubt be interesting on this account, and especially if we promise to refer to no other type of the numerous machines on the market.

*To use the "Faija" Machine.*—See that the quadrant A is in the position shown in sketch, so that the chain B to the dial C is slack, and the lever D free and balanced.



"MICHAELIS" TESTING MACHINE.

Turn the wheel E from right to left, until the lower clip F can be raised into contact with the upper clip G.

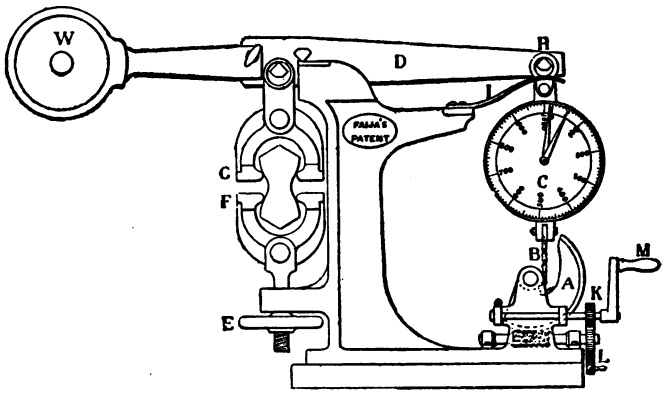
Insert the briquette to be tested in the clips, taking care that it is put in true and evenly, and so that the pull on it and the clips is true and vertical, then turn the wheel E from left to right, which will bring down the lower clip F, and secure the briquette firmly in the clips. (It is generally advisable to put such a strain on the briquette by turning wheel E that about 100 lbs. is indicated on the dial.) When in this position there should be about half-an-inch between the under side of knife edge H, and the buffer or recoil spring I.

Having seen that the pinion K is in gear with the wheel L, turn the handle M until the briquette breaks. The loose

pointer will show on the dial the strain in lbs. at which the briquette broke.

*To Return to Zero.*—Throw the pinion K out of gear with the wheel L by turning the pin and pushing the spindle to the left; turn the wheel L from left to right until the quadrant A has returned to its normal position with the chain B slack; put the loose pointer back to zero; release the lower clip F by turning wheel E from right to left; remove the broken briquette, and insert the next that is to be broken.

Reverting, however, to the general matter of the tensile test it is well known that there is a considerable variation in the




"FAIJA" TESTING MACHINE.

tensile strength of any particular cement as obtained by different observers.

Part of this variation is inevitable. The strength of Portland cement depends so largely upon the details of the method of testing, that variations in manipulation among a number of other and minor causes make an appreciable difference in the results, and the neat tensile test is therefore governed by many circumstances.

The following particulars include perhaps most of the common causes of divergent results in the tensile test:—

(1.) *Due to the cement.* Whether the cement is fresh or has been aerated, and if the latter, the period of aeration.

(2.) *Due to gauging.* The amount of water used in mixing. The quality, character and temperature of the water used in gauging. The temperature of the room. Whether the cement

is hand or machine mixed. Whether a non-porous slab is used as a mixing tray.

(3.) *Due to the preparation of briquettes.* Whether a skilled operator has been employed. Whether the mould is of wood or iron. The shape of the mould, the method of filling, and whether the mould was filled at one or several operations. Whether all air bubbles have been eliminated. Whether the mould is shaken, tapped, rammed or pressed to make the briquettes of various densities.

Whether the briquettes are kept damp during setting, and whether kept dry or in water during the period of test. Whether the briquettes are made by the same operator on the same day under the same conditions. The temperature of the water used for immersion.

(4.) *Due to the testing.* The temperature of the testing room. The length of time the briquettes have been out of the water previous to testing. The area of the breaking section. The form of the briquettes and the shape of the cross section at the point of fracture.

The nature of the strain, and whether suddenly or gradually applied, and the time occupied in applying the strain. The form of clips in the testing machine for holding the briquettes. The position of the strain as regards the breaking section of the briquettes and the preventing of cross strains. The unequal bearings of the clips on the briquettes.

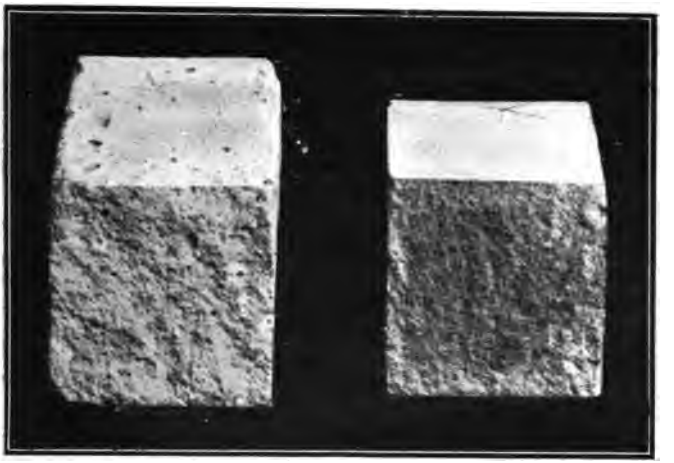
The fact that there are so many separate factors connected with the making and testing of briquettes, all of which have a distinct and definite influence on the subsequent tensile strength need not, however, unduly point to the inconsistency of the test.

For instance, the age of the cement after grinding is found to affect the tensile strength of a briquette; but as the manufacturer is responsible for the state in which the cement leaves his works, we can rely upon him looking after his own interests in this direction.

The percentage of water to be used in the gauging of briquettes is generally from 18 to 22, a proportion which varies according to the age, fineness and activity of the sample.

For briquettes of three parts sand to one of cement, about 12 per cent. of water is required (the percentage being calculated on the total weight of the sand and cement).

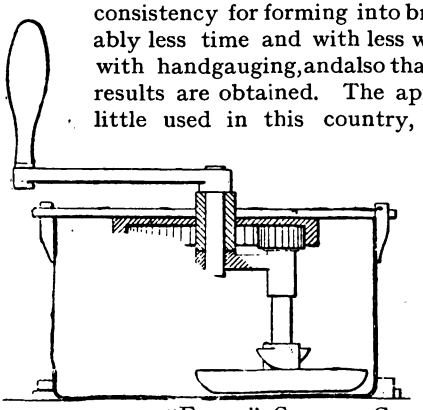
The best results are obtained with a minimum quantity of water, and a dry or stiff plastic mixture gives greater uniformity.



No. 1. No. 2.

The above reproduction of a photograph shows sections of two briquettes of the same cement, but made by two different persons. No. 1 briquette tested 320 lbs. per sq. inch and No. 2 briquette tested 580 lbs. in 7 days.

An illustration is here given of Faija's cement gauger, an apparatus for the mechanical mixing of cement and water for briquette gauging. By the use of this device it is claimed that the cement can be brought to the proper consistency for forming into briquettes in considerably less time and with less water than is possible with handgauging, andalso that better comparative results are obtained. The apparatus is, however, little used in this country, as perhaps in the absence of any standard arrangement for the normal consistency of cement in briquette making, each tester has his own ideas on the question.



"FAIJA" CEMENT GAUGER.

The water to be used in gauging must be clean and fresh, and of a temperature of about 60 to 70° Fahr. In the gauging of briquettes, the cement and water must be *thoroughly* mixed for three minutes, and then pressed into the moulds by the handle of the trowel used in gauging.

Any excess cement should be removed and the top of the briquette smoothed off level with the mould, the mould being then turned over to enable the reverse side of the briquette to be smoothed. Particular care should be taken that the mixing is carried out upon some non-absorbent substance such as a slab of slate or thick glass.

In conclusion, it should be pointed out that the accurate testing of cements for tensile strength is *not* a simple process. Some experience is necessary before the materials can be manipulated so as to obtain even approximately accurate results.

The tests carried out by inexperienced though intelligent and careful persons are usually very contradictory and inaccurate, and no amount of experience can totally eliminate the variations introduced by the personal equation of the operator.

In view also of the wholesale adulteration of otherwise good brands of cement at the present time, due, it is said, by manufacturers having to sell cement at a cheap price owing to foreign importations, the neat cement tensile test should be entirely done away with, and the strictly practical and more scientific sand test substituted.

## XII.—Compression Tests.

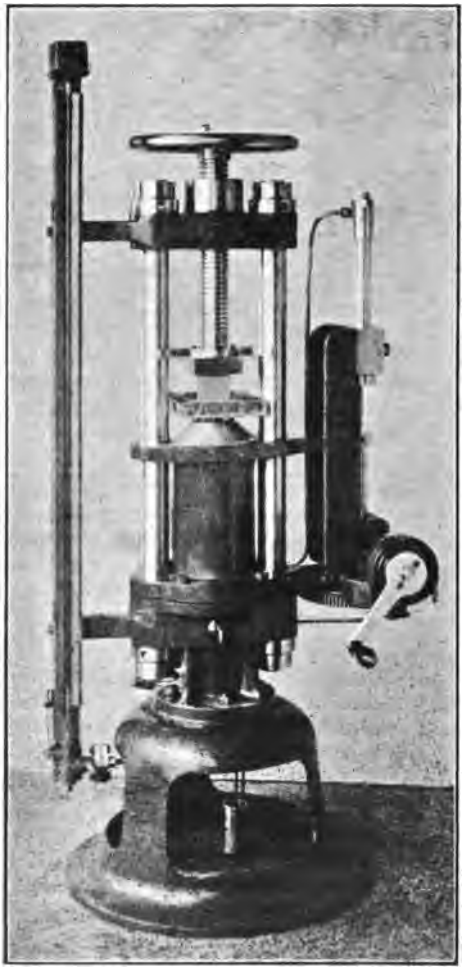
ALTHOUGH rarely carried out in this country, the test for compression, or crushing is commonly performed on the Continent, a block of cement and sand being used, about 2¾ inches square and prepared in a similar way to the briquettes. This test, as well as the transverse test is applied by the alteration of levers on one or other of the ordinary briquette testing machines, and the illustration here shows how the Fairbank's tensile testing apparatus may be adapted for the compressive test.

In order to secure uniformity in the results of testing by compression, it is preferable to make use of some mechanical process for the preparation of the test blocks.

Care must be exercised in arranging that the pressure be even all over the test block, and consequently, its two faces should be well-trowelled and smooth, and all sand or grit removed. The preparation of test blocks for compression is carried out on the Continent by well mixing 14 ozs. of cement with 42 ozs. of dry standard sand. To this is added 160 C.C. of clean water, and the mortar well stirred. Assuming that these proportions be adopted, take about 30 ozs. of the mortar, and fill into a cubical mould which can be used with the Böhmé hammer illustrated in the previous article. The iron die is then placed in the mould, and the mortar receives 150 strokes of the hammer weighing 4·4lbs.

After the preparation of the block by this process, well trowel the two faces, and put aside to set for a period of 24 hours, after the expiration of which time, place the blocks in water. The immersion lasts until the test takes place, and each block must be tested immediately it is taken from the water.

The standard machine for carrying out the compressive test is an hydraulic apparatus by Amsler-Laffon, of Shaffhausen, Switzerland. This machine tests up to 60,000 lbs. compression.



AMSLER LAFFON APPARATUS FOR COMPRESSION TEST.

In testing the cement cubes, the lower compression plate rests with a spherical surface on the piston contained in the main cylinder. The upper compression plate just touches the flat end of the screw spindle, which is only used to set the distance between the plates to the size of the test block. During the test the upper plate is at rest, whilst the lower plate is raised by the piston pressing upwards under the action of oil coming from the plunger pump, which is driven by a handle shown at the right of the illustration.

The pressure of oil in the main cylinder multiplied by the sectional area of the piston is equal to the strain on the specimen block, provided that the pistons move without friction, and this has been arranged for in the construction of the apparatus.

The oil also assists to well lubricate and tighten the piston.

The pressure exerted acts at the same time upon a thin piston which transmits its movement to a lower piston which pushes the mercury into the transparent tube of the gauge on the left of the machine. The mercury rises here to a height

FAIRBANK'S TENSILE TESTING MACHINE.

MOULD FOR COMPRESSION TEST.

such that the pressure of the column of mercury balances the pressure of the piston.

In this way, the rise of mercury is a means of measuring the pressure of the main points.

The *accuracy* of the results read off the gauge depends only on the proper working of the pistons in their cylinders. This can be controlled at any time by moving the pistons with the hand and observing that they all move smoothly. As there is neither stuffing box nor other lining for tightening the pistons, the friction will be rather smaller than greater when the machine is loaded, than unloaded, because of the slight widening of the cylinders.

The machine will improve by frequent use in consequence of the wear of any roughness on the cylinders and pistons.

As regards accuracy, the machine is, at least, equal to any good lever machine; in respect to wear and tear, it is almost indestructible, which is hardly the case with lever machines having knife edges.

No special foundation is required for the machine; the floor should only be strong enough to carry the machine safely.

Attachment to be used for Compression Test with Fairbank's Testing Machine.

## XIII.—Soundness and Variation of Volume.

THE most useful tests for cement are those which connect themselves definitely with some serious defect, to which cements are subject, or with some merit which they should possess: and thus, perhaps, the test for soundness is of paramount importance. This test can be made with the most simple apparatus—if, indeed, any apparatus is required at all—is easy of manipulation, and its results are obtained immediately. Again, the tests which we shall explain under this heading are freest from personal equation and errors due to local surroundings.

The test for soundness, indeed, at once obviates many difficulties which arise in the long-time tensile tests for the acceptance or rejection of cements, and the issue of the test for soundness is finally decisive. It cannot, however, be stated with any degree of certainty that results which may be obtained by the "hot" test—the now general test for soundness—are identical with those which may be experienced in actual construction work, but there is no doubt that if a cement is in the slightest degree unsound, the hot test will at once detect and emphasise the weakness.

Numberless methods are in vogue for ascertaining the soundness of cements, and the enquiries more generally classified under this heading are those which have reference to constancy of volume; and to this end the accelerated or boiling tests are employed in order to ascertain the exemption of the cement from undue expansion or contraction.

Although, scientifically speaking, there is no constancy of volume in Portland cement—since the setting of cement, as well as heat and cold, will modify the volume—yet practical results are obtained from the observation of pats of cement remaining over from the setting tests, and kept for this purpose in air, or immersed in water.

In a thoroughly sound cement the difference in volume is not noticeable without the aid of scientific apparatus, and the practical value of the test for constancy of volume consists in ascertaining the more common defects in the undue contraction and expansion tendencies of Portland cement.

Most of the trouble of cement users is due to the expansion of the material through over-liming and other faults in the manufacture. This causes a swelling and ultimate disintegration after the work is in place. An old-time device for the testing of over-limed cements is to mix a sample of the material with water to about the consistency of treacle, the whole being then poured into an ordinary bottle or small glass test-tube, which is shaken until full to overflowing, and then placed aside in a cool place. If the cement is over-limed, or even if the proper grinding and amalgamation of the raw materials have not been properly carried out by the manufacturer, the cement will expand in setting, and split the glass sooner or later, according to the degree of the imperfection. If, on the other hand, the cement is *under*-limed (or over-clayed), it will contract in setting, and become loose in the receptacle.

In the "bottle" test care should be taken to keep the same in a cool place of even temperature; for, if placed in a warm atmosphere or near a fire, a cracked bottle will result through expansion even if the cement be perfectly sound.

The simplest test, however, for the observation of the behaviour of cements is to make up two small pats—each about three inches in diameter and one-quarter inch thick in the centre, diminishiing to very thin edges. The pats should be gauged and placed upon pieces of glass and as soon as set—or, say, 24 hours after gauging—one of the pats is immersed in water, and the other left in the atmosphere.

Both pats should be carefully examined at regular intervals for a period of 14 to 28 days, and the first indication of any disturbance or disintegration will be detected by the appearance of small cracks round the edges, or extending from the centre of the pats. Other alterations of form will follow, such as the lifting up at the edges, or in the centre of the test pat.

A good Portland cement will show no signs of cracking, scaling, crumbling, or warping; nor, indeed, will it suffer any deviation of form whatever.

Any defect in the sample will first appear in the pat under water; but since, in this mild test, it often happens that the evidences of unsoundness are so long in appearing as to render the test of little practical value, this method has given way to the accelerated or hot-water tests.

The great value of the hot test lies in the short time which elapses before the indications of defects begin to appear, and thus attention is at once directed to weak points in the cement to be further observed or guarded against.

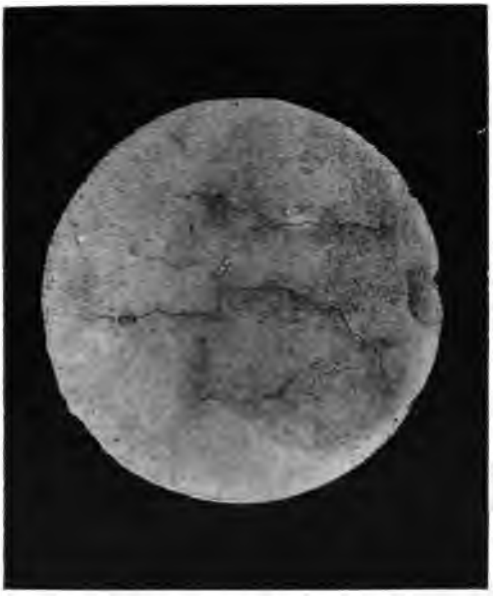
Cements which stand the accelerated tests should be used in preference to others, and such tests should be constantly applied on the work of concrete construction: for although the hot tests sometimes reject suitable material, it will always reject a material unsound by reason of the existence of active expansion.

A reliable and well-known test for the soundness of cement is that called the Faija test. It consists in subjecting a freshly-gauged pat of cement to a moist heat of 100 deg. Fahr. for six or seven hours, or until thoroughly set, and then immersing it in warm water at a temperature of 115 to 120 deg. Fahr. for the remainder of 24 hours.

This acclerated test is based on the principle that moist heat accelerates the setting of cement; and that, if judiciously applied, the age of several days may be artificially given to a cement in a few hours. A sound cement acquires great hardness in a short time when treated in this way, but an unsound one, or one that would under ordinary conditions "blow" when used in work, is caused to develop this characteristic in a few hours; and hence, by the use of this test, a definite opinion may be formed as to whether or no a cement is a safe one to use; independently, of course, of its tensile strength, which may or may not be equal to that required.

The apparatus consists of a covered vessel, in which water is maintained at an even temperature of from 110 deg. to 115 deg. Fahr.; the space above the water is, therefore, filled with the vapour arising therefrom, and is at a temperature of about 100 deg. Immediately the pat is gauged, it should be placed on the rack in the upper part

of the vessel, and in five or six hours it may be placed in the warm water and left therein for nineteen or twenty hours. If at the end of that period the pat is still fast to the glass, or shows no sign of blowing, the cement may be considered perfectly sound; should, however, any signs of blowing appear, the cement should be laid out in a thin layer for a day or two, and a second pat made and treated in the same manner, as the blowing tendency may only be due to the extreme newness of the cement.



CONTRACTION CRACKS.

Another, and perhaps readier, test for soundness, is as follows:—Prepare simple pats of cement in the ordinary way, and after 24 hours, place them in a receptacle of cold water, which should then be heated gradually to boiling point; allow to boil for two to four hours. If the material is intact, it will be found thoroughly satisfactory in the constructional work.

Contraction cracks in the test pat are not necessarily a sign of bad quality, but are perhaps more generally found to be due to faulty testing rather than to a deterrent quality in the nature of the cement. A cement which is over-clayed will contract, but contraction cracks are found also if the test pats, when moist, are left in the sun or in a dry atmosphere, or even if the drying takes place too rapidly in draughts of air.

EXPANSION CRACKS.

These contraction cracks, as distinguished from those caused by expansion, are irregular lines in the centre of the sample pat, and are often caused by placing the mixed cement on a dry, porous plate; an excess of water, too, in the gauging will cause a shrinkage or contraction.

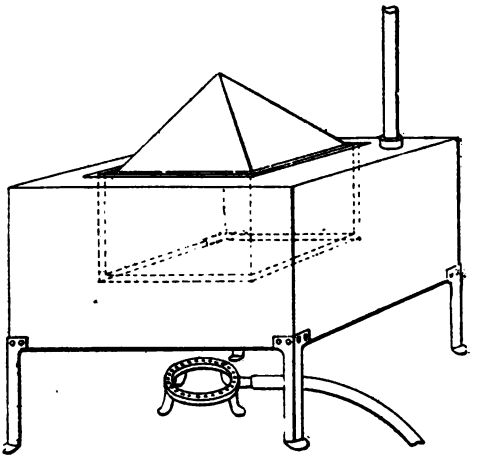
An expansion crack, however, will be found to commence upon the outer edges of the pat, and run towards the centre. This is by far the more serious defect.

The expansion of cements is generally caused by what is known as "free" or uncombined lime, and this is introduced

into the product either by the careless or unscientific mixing of the raw materials used in the manufacture, or by the incorporation of underburnt clinker from the kilns.

If a cement is poorly manufactured, the aeration or atmospheric slaking will eliminate, to some extent, what free lime may be present, but a properly manufactured cement will withstand the hot or boiling tests as soon as the material is taken from the grinding mills, and any period of aeration other than the time elapsing between the grinding into the manufacturers' stores and the loading of the cement into trucks is unnecessary.

A system of hot testing, which gives a quantitative expression to the unsoundness of cement, is that devised by Deval, a Continental expert. This test was explained in the technical papers about 1891, and since the majority of English cements fail to pass the test, it is considered one that is needlessly severe. The theory of Deval seems to establish the fact that in most cases a 3 to 1 sand and cement briquette, kept in water at a temperature of 176°F. (80° C.) for 2 days has the same tensile strength as one kept in water at the ordinary temperature for seven days, while a similar comparison is observed in the case of briquettes kept in water at 170° F. for seven days, and those kept in water at the ordinary temperature for 28 days.

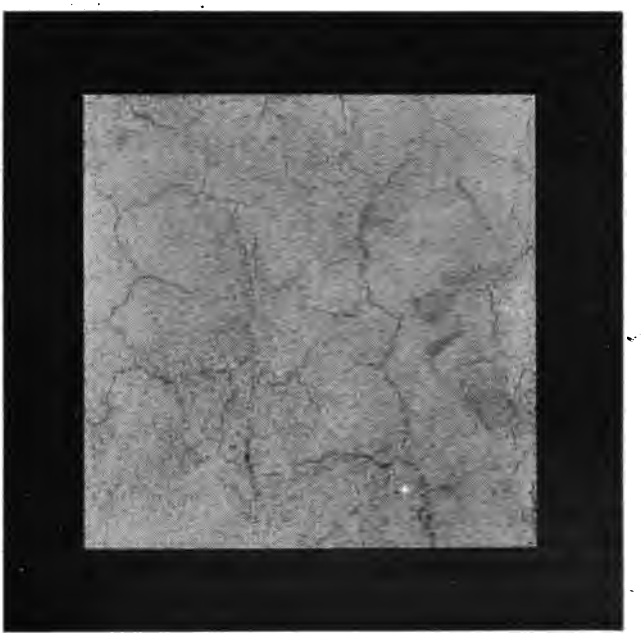


DEVAL HOT WATER BATH.

The results of this test, as applied to a good quality Portland cement, are here given.

The tensile strength of briquettes, 3 parts of sand to 1 of cement, kept in water at 80° C. (= 176° F.) for 2 and 7

days is compared with that of similar briquettes kept in water at the ordinary temperature for 7 and 28 days respectively.



SUPERFICIAL CRACKS OR "CRAZING" IN CEMENT WORK.

BREAKING STRAIN OF BRIQUETTES 1 IN. by 1 IN. SECTION.

| 2 Days. HOT. | 7 Days COLD. | 7 Days. HOT. | 28 Days. COLD. |
|---|---|---|---|
| lbs. | lbs. | lbs. | lbs. |
| 230 | 310 | 285 | 370 |
| 210 | 310 | 270 | 360 |
| 200 | 300 | 250 | 350 |
| 200 | 300 | 250 | 350 |
| 190 | 290 | 240 | 340 |
| 190 | 290 | 215 | 300 |
| 1220 | 1800 | 1510 | 2070 |
| 203⅓ | 300 | 251⅞ | 345 |

The results indicate the cement to be perfectly sound and free from all tendency to blow.

Perhaps we should also here deal with a fault which many cement users consider to be due to the unsoundness of the cement, and that is a defect commonly seen in concrete work and known as "crazing" or fine superficial cracking. These cracks (sometimes also called "hair" cracks) appear on cement work or artificial stone after weathering, and although a very unsightly appearance is presented, this is the full extent of the deterioration. The defect, which is not the fault of the cement, can be entirely avoided by adapting the treatment of the materials to the work in hand. That this "crazing" or fine cracking, which is illustrated here, originates in the manipulation of the concrete is proved by the fact that the same defect occurs in work carried out with the soundest and best made cements. These hair cracks appear to connect themselves wholly with a mortar too rich in cement. When facing or dressing, the surface work or veneer must be well rubbed down to the concrete base of the stone work.

No cement should be used in the dressing of concrete work without being well mixed with sand or other very fine aggregate, for the superficial cracks are caused by the natural variation in volume of the neat cement face of the stonework being disproportionate to the concrete bulk.

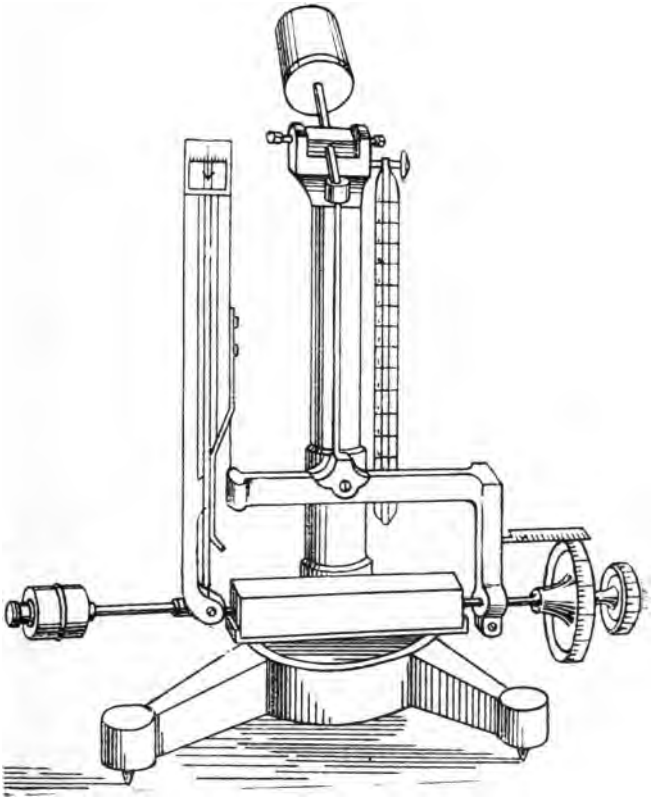
## Constancy of Volume.

The condition for testing the alteration in volume of cements is entirely, by the above-mentioned processes, a qualitative one, but this may be made a useful scientific test by the aid of the Bauschinger apparatus here illustrated, and which we believe is the only arrangement of the kind at present upon the market.

The Bauschinger apparatus is a simple and accurate method of ascertaining the conclusions set forth relating to Portland cement alone as being by far the most important of hydraulic cement. It consists of a stirrup shaped calliper having a fine micrometer screw on its right arm, the left taking the support of a sensitive lever. The shorter arm of this lever ends in a slightly rounded calliper point and

is pressed towards the measuring screw by a plate spring attached to the long arm. The callipers may be readily moved in any direction.

The test pieces of cement or concrete are prepared in special moulds, and the measuring of a test piece requires only a few minutes.

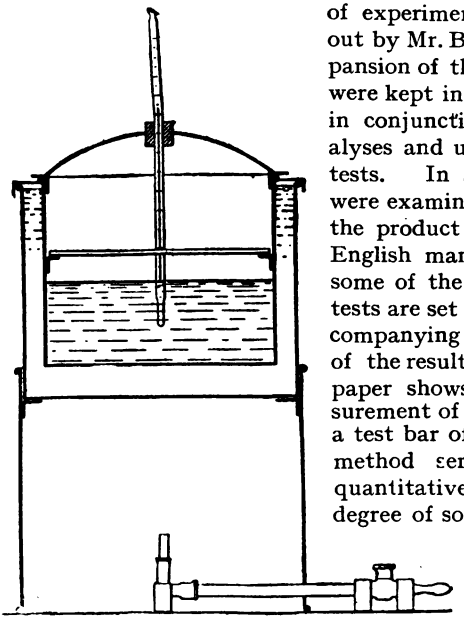


BAUSCHINGER'S APPARATUS.

For the purposes of a paper submitted in 1901 to the Budapest Congress of the International Association for testing materials, the author (B. Blount) gives some information respecting the alteration of the now general form of the hot test to that of rendering this test a quantitative expression.

For observing the expansion and contraction tendencies of cement we have referred to the hot and cold water pat tests, and the dry heat and bottle tests, but these do not contain the scientific or conclusive data afforded by a well-devised and properly executed hot test for constancy of volume, useful for both the acceptance and rejection of cements. The usual cold water pat tests, such as are prescribed in the normal rules adopted by various countries, are not considered sufficiently stringent, and for many years past all cements have been required to pass some form of hot test.

This test, although of undoubted utility, is, however, purely qualitative, and in the paper under notice it has been sought to put it on a quantitative basis. For this purpose rectangular bars of cement were prepared, suitable for measurement in the Bauschinger apparatus, and a series of experiments were carried out by Mr. Blount on the expansion of these bars, which were kept in water at 45° C., in conjunction with the analyses and usual mechanical tests. In all, 68 cements were examined, representing the product of five leading English manufacturers, and some of the results of these tests are set forth in the accompanying tables. A study of the results given in the paper shows that the measurement of the expansion of a test bar of cement by this method serves to give a quantitative expression of its degree of soundness—a very desirable adjunct in cement testing. When the cement is perfectly sound the test bar, 100 millimeters in length, expands but little



FAIJA'S HOT WATER APPARATUS.

that is, 10 units of one-hundredth millimeter; but if the test pat is not quite sound, the bar expands from 20 to 30 units.

When the cement is markedly unsound the expansion is enormous, and so impressed is the author by the advantage secured in establishing a recognised and valuable hot test on a quantitative footing, that several recommendations have been drawn up for the constancy of volume of cements among which are the following :—

The best method of determining the constancy of volume of Portland cement is to measure the expansion of test-pieces kept under conditions which accelerate those chemical reactions on which the setting and hardening of the cement depends.

The best practical method of accelerating these chemical reactions is by exposing the test pieces to a moderately high temperature, say, between 40° and 50° C.

| ANALYSIS. | | | | |
|---|---|---|---|---|
| Silica ($SiO_2$) .. .. .. | 21·60 | 21·70 | 21·34 | 20·80 |
| Insoluble residue .. .. | 1·08 | 1·02 | 0·88 | 0·96 |
| Ferric oxide + Alumina ($FeO_2 + Al_3O_2$) .. | 11·06 | 10·68 | 10·70 | 10·92 |
| Lime ($CaO$) .. .. .. | 62·64 | 62·04 | 62·40 | 62·22 |
| Magnesia ($MgO$) .. .. | 1·01 | 1·11 | 1·09 | 1·09 |
| Sulphuric anhydride ($SO_3$) .. | 1·37 | 1·68 | 1·36 | 1·37 |
| Carbonic anhydride + Water ($CO_2 + H_2O$) .. .. | 0·96 | 0·76 | 1·46 | 1·52 |
| Alkalies and loss .. .. | 0·28 | 1·01 | 0·77 | 1·12 |
| | 100·00 | 100·00 | 100·00 | 100·00 |
| Specific Gravity .. .. | 3·160 | 3·175 | 3·150 | 3·150 |
| Tensile strength neat, pounds per sq. inch at 7 days .. | 570 | 512⅓ | 518⅓ | 595 |

Measurement of the expansion of the test pieces may be effected in any convenient manner.

BAUSCHINGER TESTS.

Expansion of a bar, 100 mm. in length in units of $\frac{1}{100}$ mm.:

| | | | | |
|---|---|---|---|---|
| COLD 1 days | + 1·5 | + 3·5 | + 2·5 | + 2·5 |
| 2 ,, | + 3·5 | + 6·0 | + 8·5 | — |
| 3 ,, | + 6·0 | + 8·0 | — | — |
| 4 ,, | — | + 9·0 | — | — |
| 5 ,, | — | — | — | — |
| 6 ,, | — | — | — | + 11·5 |
| 7 ,, | — | + 11·5 | + 8·5 | — |
| 8 ,, | — | + 11·5 | + 9·5 | — |
| 9 ,, | — | + 12·0 | + 9·5 | — |
| 10 ,, | — | + 12·0 | — | — |
| 11 ,, | — | + 12·0 | — | — |
| 12 ,, | — | — | — | — |
| HOT 1 days | + 16·0 | + 9·5 | + 9·0 | + 14·0 |
| 2 ,, | + 31·0 | + 13·5 | + 17·5 | — |
| 3 ,, | + 49·5 | + 19·5 | — | — |
| 4 ,, | cracked develuted | + 22·0 | — | — |
| 5 ,, | — | — | — | — |
| 6 ,, | — | — | — | cracks appeared |
| 7 ,, | — | + 26·5 | + 17·0 | — |
| 8 ,, | — | + 27·5 | + 18·5 | — |
| 9 ,, | — | + 28·0 | + 18·5 | — |
| 10 ,, | — | + 28·0 | taken as constant | — |
| 11 ,, | — | + 28·0 | — | — |
| 12 ,, | — | — | — | — |

A test bar of neat cement, 100 millimeters in length, and kept in water at 45° C., should attain constancy of volume in seven days, and should not expand more than 0.2 millimeter, as well as it should be absolutely free from cracks. The test for constancy of volume in its qualitative form, that is, by observation of the behaviour of a pat of cement, instead of the measurement of a bar, is one, moreover, now very generally carried out, and there is no difficulty in obtaining a cement which will pass this test.

## XIV.—Specifications.

TO the multiplication of specifications for the supply of cement there appears to be no finality, and perhaps in an article under this heading it would be best to refrain even from recapitulating or criticising the tedious and voluminous literature that has already appeared on the subject of cement specifications, and the existence of which has made confusion worse confounded.

Although it is true there are in existence a number of thoroughly scientific and practically useful specifications, it is obvious that in the interests of the great and growing number of cement users a standard specification of quality is necessary.

It is a fact that at the present time hardly any two sets of specifications agree, and the idea appears to be prevalent that all and every engineer, architect, surveyor, contractor and builder, as well as, indeed, everyone who buys cement, must have an original—extremely original in some cases—specification of his requirements.

The manufacturer, however, does not make a special material of the varying and often impossible qualities demanded, and his object is to manufacture a product of good, sound quality, and a cement which he knows will give general satisfaction in use. If, then, the matter of specifications has arrived at so impossible a point, it appears necessary that—given that the character of cement to be used be rigorously inquired into—one common statement of quality should be sufficient for all reasonable requirements. With the widely varying qualities of cement at present on the market—and never was there more need for testing even the best-known brands of cement than in this age of adulterated materials—the specification of requirements should be scientific, practical, and, above all, compatible with common sense.

Take, for instance, the point of fineness of grinding, a modern improvement in the manufacture of cement. As one glances through the specifications of to-day, it is seen that one party requires the most finely-ground product possible; another demands that the cement shall not be too fine, and specifies a maximum percentage of flour; and yet another shows that he is satisfied with the coarsest material, in stating that the residue must not exceed 10 per cent. on a 50 by 50 mesh sieve. Of course, the finely-ground cement will satisfy most requirements, the only exception being the case where an extravagant specification gives the maximum percentage of flour in the cement to be supplied. This is an instance too often met with, and generally indicates the lack of an intelligent perusal of the results of the modern investigation of cements.

A specification to the effect that a cement shall *not* contain more than a certain percentage of flour is at once at variance with a knowledge of the practical value of the product (which is well known to increase with the fineness of grinding) and with the rudimentary science of the subject, although so much may depend upon the material when incorporated into the constructional work. There appears to be an innate prejudice in the minds of some cement-users against any product which in fineness of grinding, tensile strength or analysis may differ from the material of earlier days. Such a prejudice displays a deplorable ignorance both of the science of cement manufacture and use and of the increased utility and economy of the modern product.

A number of specifications to-day are formed with a similar disregard of quality, and perhaps the unnecessary length and technicality of the average specification is accountable for the obvious lack of interest in cement-testing generally; but it should not be concluded that because a specification may contain the strict requirements of every known test for quality that the end in view is thereby assured. Although the variety of tests for cement may be extremely useful, and may, moreover, afford valuable information for scientific research and for the improvement of the product, yet what practical utility is there in the majority of specifications now in existence?

Let us classify, for example, the common tests of cement under the two headings of strength and soundness—the two vital qualities of the material. We have tests for weight and specific gravity, setting, fineness, tensile strength, soundness and compression.

The tests for weight and specific gravity are not of much practical importance, and are only carried out in the usual laboratory testing of samples.

The tests for fineness, tensile strength and compression all connect themselves with strength, and can be readily and more efficiently dealt with by a general sand test for tensile strength. The other test of importance—that of soundness—brings the science of cement-testing under the two headings referred to above, and thus we have the vital qualities of cement expressed by two tests, namely :—

1. Sand test for tensile strength.
2. Accelerated test for soundness.

In the opinion of the writer, those two tests are the only necessary details that a cement-user need be well-informed upon for general purposes, and although the fuller information mentioned in the foregoing articles is extremely interesting and enlightening to those making cements a scientific study, yet for all practical and every-day inquiry the sand test for strength and the hot test for soundness are all that is required.

In support of this statement, we will examine these two tests in detail.

The sand test renders unnecessary the neat tensile test for strength, and is more useful and practical. The observation of setting is more direct by the sand test than by neat cement tests, and can be as readily ascertained from the briquettes as from the pats made for the latter purpose. Moreover, the value of the test for fineness of grinding can only be shown by the sand test, which also asserts its importance by showing up the unsatisfactory quality of adulterated cements. In the remaining tests for soundness, we would suggest the doing away with all apparatus and instructions for working according to experts' varying theories, and the substitution of a "hot" test with neat cement—simple in its operation yet severe in its methods, and quite as certain in its results.

To ensure the standardisation of this, the simplest of specifications, let the sand tests be carried out with a suitable and good quality sand to be universally supplied to cement manufacturers and users from one common source, and let this aggregate be generally recognised by the trade for standard cement-testing purposes.

This sand should be so fine as to all pass through a 20 by 20 mesh sieve and be retained on a 30 by 30 mesh sieve, the wire of such sieves having respectively a thickness of ·0164 of an inch (No. 27 British Standard Wire Gauge) and ·0108 of an inch (No. 32 B.S.W.G.).

Then the specification, which will absolutely ensure quality of product, scientific methods of manufacture, and high commercial value, and will, in addition, avoid all unnecessary trade technicalities, may read as follows :—

*Tensile Strength.—Briquettes gauged by hand with three parts of the standard testing sand and one part of cement (both by measure) shall remain in a damp atmosphere for 24 hours after gauging, and be then immersed in water for a total period of seven and twenty-eight days, when they must bear a minimum tensile strength, as follows :—*

| | *Per sq. inch.* |
|---|---|
| *7 days' test* .. .. .. .. .. | 200 *lbs.* |
| *28 days' test* .. .. .. .. .. | 250 *lbs.* |

*Soundness.—Pats made from a thick liquid consistency of neat cement shall, after a period of 24 hours allowed for setting, be immersed in a receptacle of cold water, which shall then be heated to boiling, and the pats remaining for three hours under this heat must be thoroughly sound in every respect.*

The material showing the best results under the above tests will undoubtedly be the best quality product, and no number of additional tests will show the good or bad quality more readily or more surely than the above short specification.

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Another specification recently put before the Society of Engineers is as follows, and commends itself as a standard in its simplicity and in its stringency.

The whole of the cement shall be pure Portland cement, and shall conform to the following tests :—

*Fineness of Grinding.*—To be such that, when sifted through a standard sieve having fifty holes per lineal inch, there shall not be more than one-half ($\frac{1}{2}$ per cent.) by weight

of residue ; when sifted through a sieve having seventy-six holes per lineal inch, there shall not be more than five (5 per cent.) of residue ; and when sifted through a sieve having 100 holes per lineal inch, there shall not be more than twelve (12 per cent.) of residue.

*Time of Set.*—A pat of neat cement gauged with the minimum of water at the normal temperature (60 deg. Fahr.), and placed on a glass or other non-porous slab shall not commence to set in less than eight minutes, or take longer than five hours to set hard.

*Soundness, or Freedom from Expansion and Contraction.*—A pat submitted to moist heat and warm water in the Faija apparatus for soundness at the usual temperatures, viz., 110 deg. Fahr. and 120 deg. Fahr. respectively, shall show no cracks or signs of expansion after twenty-four hours.

*Tensile Strength.*—Briquettes of neat cement, gauged with the minimum of water on a non-porous bed and placed in water twenty-four hours after gauging, shall carry an average tensile strain of not less than 350 lbs. per square inch after three days, 450 lbs. after seven days, and 550 lbs. after twenty-eight days from the time of gauging.

Briquettes composed of 3 parts of standard sand to 1 part of cement, by weight, treated as above, shall carryan average tensile strain of not less than 150lbs. per square inch at seven days, and 250 lbs. at twenty-eight days, from the time of gauging ; but no matter how much greater strength may be developed at the earlier dates, both neat and sand briquettes must develop an increase of at least 50 lbs. between each date.

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For the information of readers, we will here give the standard specification for Portland cement, as arranged by the Society of Engineers in Canada, and we have also appended copies of some of the specifications issued by the Department of the British Government and others.

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The whole of the cement is to be well-burned pure Portland cement, of the best quality, free from free lime, slag, dust, or other foreign material.

1. *Fineness.*—The cement shall be ground so fine that the residue on a sieve of 10,000 meshes to the square inch shall not exceed 10 per cent. of the whole by weight, and the whole of the cement shall pass a sieve of 2,500 meshes to the square inch.

2. *Specific Gravity.*—The specific gravity of the cement shall be at least 3.09, and shall not exceed 3.25 for fresh cement; the term "fresh" being understood to apply to such cements as are not more than two months old.

3. *Tests.*—The cement shall be subjected to the following tests: (*a*) *Blowing Test:* Mortar pats of neat cement, thoroughly worked, shall be trowelled upon carefully cleaned 5 in. by 2½ in. ground-glass plates. The pats shall be about ½ in. thick in the centre and worked off to the sharp edges at the four sides. They shall be covered with a damp cloth and allowed to remain in the air until set, after which they shall be placed in vapour in a tank, in which the water is heated to a temperature of 130 deg. F. After remaining in the vapour six hours, including the time of setting in air, they shall be immersed in the hot water and allowed to remain there for 18 hours. After removal from the water the samples shall not be curled up, shall not have fine hair cracks nor large expansion cracks, nor shall they be distorted. If separated from the glass, the samples shall break with a sharp crisp ring. (*b*) *Tensile Test* (*Neat Cement*): Briquettes made of neat cement, mixed with about 20 per cent. of water, by weight, after remaining one day in air in a moist atmosphere shall be immersed in water, and shall be capable of sustaining a tensile stress of 250 lb. per square inch after submersion for two days, 400 lb. per square inch after submersion for six days, 500 lb. per square inch after submersion for 27 days. The tensile test shall be considered as the average of the strength of five briquettes, and any cement showing a decrease in tensile strength on or before the twenty-eighth day shall be rejected. (*Sand and Cement*): The sand for standard tests shall be clean quartz, crushed so that the whole shall pass through a sieve of 400 meshes to the square inch, but shall be retained on a sieve of 900 meshes per square inch. The sand and cement shall be thoroughly mixed dry, and then about 10 per cent. of their weight of water shall be added, when the briquettes are to be formed in suitable moulds. After remaining in a damp chamber for 24 hours the briquettes shall be immersed in water, and briquettes made in the proportion of 1 of cement to 3 of sand, by weight, shall bear a tensile stress of 125 lb. per square inch after submersion for six days, and 200 lb. per square inch after submersion for 28 days. Sand and

cement briquettes shall not show a decrease in tensile strength at the end of 28 days or subsequently.

4. The manufacturer shall, if required, supply chemical analyses of the cement.

5. *Packing.*—The cement shall be packed either in stout air and water tight casks, carefully lined with strong brown paper, or in strong air and water tight bags.

6. The manufacturer shall give a certificate with each shipment of cement, stating (1) the date of manufacture; (2) the tests and analyses which have been obtained for the cement in question at the manufacturer's laboratory; (3) that the cement does not contain any adulteration.

WAR OFFICE DEPARTMENT SPECIFICATION.

*Quality.*

1. The whole of the cement to be highly burnt pure Portland cement, of best quality, but not over or under burnt, and to be made entirely of chalk and clay, free from lime, Kentish rag, slag or other foreign materials mixed with it after the cement has left the kiln.

*Lime.*

2. The cement must contain no appreciable amount of magnesia, and the percentage of lime shall be within the limits of 60 to 62.

*Fineness of Grinding.*

3. To be such that when sifted through a standard sieve, having 50 holes per lineal inch (2,500 meshes per square inch, wires to be of brass, and .007 inch in diameter), there shall not be more than 2 per cent. by weight of residue; and when sifted through a sieve having 76 holes per lineal inch (5,776 meshes per square inch, wires to be of brass, .005 inch in diameter), there shall not be more than 10 per cent. by weight of residue.

*Testing tensile strength, etc.*

4. The cement for testing to be taken from different parts of the parcel. It is to be mixed with just sufficient water determined by trial, to produce when ready for the mould a smooth, easily workable paste that will leave the trowel in a compact mass. The percentage of water by weight not to exceed 20 per cent.

Not more than four minutes after mixing, the gauged cement to be worked into the moulds, all air bubbles being thoroughly worked out.

As soon as the briquettes are set, as described in paragraph 5, they will be removed from the moulds, and 24 hours after gauging they will be placed in water until tested.

The tensile strength to be such that the briquettes will sustain before breaking 400 lbs. on the square inch seven days after gauging.

An average of the breaking strain of six briquettes to be taken as the tensile strength.

The strain to be applied at the rate of 100 lbs. in 15 seconds.

*Setting.*

5. The time of setting when fresh is to be not less than 20 minutes, and will be determined in the following manner :—As soon as each briquette is gauged the time will be taken, and at frequent intervals a needle having a flat end $\frac{1}{10}$ of an inch square, and weighted to a total of 2½ lbs., will be applied to the surface of the cement. When the end of the needle fails to make an impression upon the surface the time will again be noted, and the difference between the second and first readings will be considered the time of setting for each pat or briquette ; the mean of these times will be taken as the time of setting for the batch of cement to which the series of tests apply.

*Soundness.*

6. Two pats gauged with a minimum amount of water and placed on glass or iron plates, one of which is to be placed under water after setting as in paragraph 5, the other to remain in air, shall after seven days show no signs of cracking, crumbling, or alteration of form.

*Weight.*

7. The cement to weigh not less than 110 lbs. per striked imperial bushel, filled into the measure as lightly as possible, by sliding it down an inclined board, the bottom edge of which is to be kept slightly above the surface of the cement as it rises in the measure.

*Inspection.*

8. An inspecting officer, on behalf of the War Department, will examine and test the cement, and he shall have free access to the contractor's works within working hours during the continuance of the contract. He will take samples from the cement when in bulk, from which the test briquettes and pats shall be gauged, in such a manner as he may determine.

Cement required for home stations will be tested on receipt at the place of delivery. The apparatus for the testing at home will be supplied by the war department.

*Assistance to Inspecting Officer.*

9. The contractor shall afford every assistance to the inspecting officer when making his examination and tests at the works, and is to provide for his use such testing apparatus and appliances of a satisfactory and approved character as he may require for testing the cement at the contractor's works; all charges for the delivery of samples to the inspecting officer's office to be paid by the contractor.

*Testing, where to be done.*

10. The gauging, testing and breaking will be done either at the contractor's works, or at the office of the said inspecting officer, as the latter may determine.

*Casks.*

11. For containing 200 lbs. and 400 lbs. of cement are to be made of sound thoroughly seasoned fir, straight in grain and free from large or loose knots; each cask to be bound with four new strong iron riveted hoops and ten wooden hoops; the staves to be full ½ inch thick and not more than three inches wide; the casks to be well trussed, and the joints of staves to be close throughout, the heads and bottoms to be firmly secured with crosspieces, and wooden hoops inside and outside; all nails securing the hoops to be clinched on the inside. All casks to be lined with stout brown paper, to prevent leakage. The casks to be finished in a thorough workmanlike manner, and to be equal to the sample submitted by contractor, and approved by the inspecting officer as the standard sample.

No charge shall be made for weighing, filling, closing, marking, stowing, or direction.

Each cask to be marked W ⅄ D in two places.

*Sacks.*

12. The sacks to be well made, and equal to the sample submitted by contractor, and approved by inspecting officer as the standard sample.

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INDIA OFFICE.—SPECIFICATION OF PORTLAND CEMENT.

1. Notice in writing is to be given to the superintendent, India Store Depot, when the contractor is ready to begin the grinding of the cement.

2. The cement is all to be of the best quality and of such a density that when a week old the specific gravity shall not be less than 3.1.

3. The cement must be made entirely from well-burned clinker, ground to such a degree of fineness that the whole will pass through a sieve made from wire .007 inch diameter, having 2,500 meshes per square inch, and that 90 per cent. by the weight of the whole will pass through a sieve made from wire .005 inch diameter, containing 5,776 meshes per square inch, in each case without rubbing. No powder or imperfectly burned material is to be ground up with the clinker.

4. Samples of the cement will be taken at the contractor's works as often as may be deemed necessary by the superintendent of the India Store Depot or his deputy, and at least one sample for every 90 tons ground is to be sent carriage paid to the oil branch, India Store Depot. From these samples test briquettes will be gauged and moulded, and placed in fresh water 24 hours after gauging, and will remain under water till tested. The water use in gauging the cement is not to be less than 20 per cent. (by weight) of the cement.

5. After six days' immersion the briquettes will be subjected, in a machine at the India Store Depot, to a tensional strain, applied at the rate of 100 lbs. in 25 seconds, of not less than 400 lbs. on a section of one square inch, and after 13 days' immersion to a tensile strain similarly applied of not less than 450 lbs. per square inch. Three briquettes are to be tested for each test, and the average of these to be taken as the tensile strain.

6. Pats ½ inch thick, gauged as above, are not to show any cracks or alterations of form whether left in the air or under water, and when broken must be uniform in colour and hardness throughout the section.

7. On analysis, the cement must be found to contain not more than 61.5 per cent. lime, 1.25 per cent. magnesia, sulphides and sulphates equivalent to 1.75 per cent. sulphuric acid, and not less than 23 per cent. silica, and 12 per cent. alumina and oxide of iron.

8. Cement which will not stand the above tests will be rejected.

9. *Packing.*—The cement is to be packed in casks, which are to be made of sound well-seasoned fir, closely jointed.

10. Casks to contain 400 lbs. net are to be bound with four new strong iron hoops and 12 wooden hoops. The heads are to have a cross bar, not less than $3\frac{1}{2}$ inches wide, to strengthen them. The bottoms are to have a hoop strongly nailed outside, and the heads are to be secured by two hoops on each, one inside and one outside.

11. All nails which pass through the staves of the casks are to be hammered down.

12. The casks are to be lined throughout with stout brown paper.

13. A sample cask, and two sample sheets of paper, are to be submitted for the approval of the superintendent, India Store Depot, before packing the cement. They are to be addressed to the *Oil Branch*, and advised by a delivery note (Form 140) similarly addressed.

14. The address (*as given in the schedule*), description of contents, gross and net weights, and such shipping marks as may be required by the superintendent, are to be stencilled in oil paint on each cask. The contractor to provide the stencil plates.

THE ADMIRALTY.—SPECIFICATION FOR THE SUPPLY OF PORTLAND CEMENT.

*Quantity of Cement required.*

1. The quantity of cement required is tons, which is to be delivered (*a*)

*Delivery of Cement.*

2. The cement is to be delivered at the Contractor's expense, and in his own sacks, which must be in good condition. The cement to be delivered to the Naval establishment by either of the following means :—

(*a.*) By rail or cart or other conveyance, and where directed if by land.

(*b.*) By water alongside an Admiralty wharf where directed.

If the latter, the contractor will be required to supply all labour necessary on board the ship for removing the cement to the ship's side or slinging it, but all cranage and labour on wharf will be provided by the Admiralty, unless otherwise provided in the contract.

With each delivery, the contractor must send to the officer in charge of works at H.M. an invoice stating

the quantity delivered, the number of sacks, and the name and address of the manufacturer of the cement, if it has not been manufactured by the contractor.

*Failure to Deliver.*

3. Should the contractor fail to deliver the stipulated quantity of cement at the proper times, and of the proper quality, he shall pay as liquidated damages for non-delivery a sum not exceeding 1s. per ton per week for every week up to six weeks during which such cement remains not delivered. At the conclusion of the said six weeks the Admiralty shall be at liberty to cancel the unexecuted portion of the contract and obtain the cement elsewhere.

*Receipt of the Cement.*

4. The net weight of the cement delivered on the works will be paid for. This weight will be ascertained by weighing 10 per cent. of the sacks of cement as delivered, taken indiscriminately, and, deducting the tare, on the net resulting weight per sack thus ascertained, the total net quantity of cement will be estimated and paid for; or the whole of the cement may be passed over a weighbridge, where one is available, at the option of the officer in charge of works. Sacks damaged and palpably deficient will be set aside and dealt with separately.

*Testing.*

5. The cement will be tested by an officer or inspector hereinafter called the inspector, appointed by the director of works, who will visit the contractor's premises and take samples of the cement for testing at such times and in such a manner as he may think fit. For this purpose the inspector is to have free access to the contractor's premises at all reasonable times, and the contractor is to afford him every facility for inspection, and for taking samples and testing. He is also to provide, if required, free of charge, and to the satisfaction of the inspector all apparatus required for testing the cement at the manufactory.

*Storing at Manufactory for Inspection.*

6. All cement for this contract must be ground into a perfectly clean and empty bin or part of a warehouse properly partitioned off. Each parcel of cement offered must not exceed 250 tons, and if possible the depth of the heap in each bin should not exceed 5 feet. In cases where the maximum of 5 feet is not practicable special arrangements must be made or appliances provided to enable the

inspector to take a thoroughly representative sample from the heart of the mass.

*Disposal of Sacks.*

7. No charge is to be made for the use of the sacks in which the cement is delivered. They may be retained by the Admiralty for a period of one month after delivery. They will then be returned to the contractor in any way he wishes, but at his own expense. All reasonable care will be taken of the sacks, but the Admiralty will not be answerable for any injury that may be done to them, nor for loss after they have been sent from the Admiralty premises. If the sacks be retained by the Admiralty beyond one month, the contractor may call upon the Admiralty to return them to him within seven days; or, failing to do so, to purchase the sacks from him, at the rate of 8d. for each perfect sack.

*Quality.*

8. The cement is to be pure Portland, manufactured solely from chalk and clay of the best possible quality, and in very way suitable for use in engineering works of the heaviest character. It must be free from all admixture of Kentish rag, slag, or any other diluting or adulterating material whatever, and the contractor must furnish to the officer in charge of works a certificate to this effect with each consignment.

*Weight of Cement to be recorded.*

9. The weight per cubic foot of the cement in a dry uncompressed state is to be taken as a record in connection with the specific gravity and fineness, when submitted for examination on the maker's premises, and immediately after aeration on the works, samples being taken from different parts.

*Setting.*

10. The time of setting when fresh is not to be less than 20 minutes, or more than $3\frac{1}{2}$ hours after seven days' aeration, and will be determined in the following manner:— As soon as each briquette is gauged the time will be taken, and at frequent intervals a needle having a flat end $\frac{1}{10}$ of an inch square, and weighted to a total of $2\frac{1}{2}$ lbs., will be applied to the surface of the cement. When the point of the needle fails to make an impression upon the surface the time will again be noted, and the difference between the second and first readings will be considered the time of

setting for each pat or briquette; the mean of these times will be taken as the time of setting for the batch of cement to which the series of tests apply.

*Fineness.*

11. The cement is to pass through a sieve 50 by 50 = 2,500 meshes per square inch, wires to be of brass and .007 inch in diameter, with a residue not exceeding 2½ per cent. by weight, while on a sieve 76 by 76 = 5,776 meshes per square inch made of brass wire .005 inch in diameter, the residue must not exceed 10 per cent. by weight.

*Tensile Strength.*

12. The tensile strength is to be such that briquettes cast in the form shown on margin, giving to the briquette a minimum section of 1½ inches by 1½ inches, will sustain before breaking 350 lbs. on the square inch seven days after gauging. The strain upon the briquettes will be applied at the rate of 100 lbs. in 15 seconds.

An average of the breaking strains of six briquettes will be taken as the strength of the cement.

The samples for testing will be taken from different parts of the parcel or bulk in such a manner as the inspector may think fit, so that the cement tested may be thoroughly representative of the whole batch. After cooling, to the satisfaction of the inspector, the neat cement will be mixed with just sufficient water, determined by trial, to produce, when ready for the mould, a smooth, easily workable paste, that will leave the trowel in a compact mass. The gauged cement is then to be at once filled into the moulds, and all air bubbles thoroughly worked out. As soon as the briquettes are set, they are to be removed from the moulds, and at the expiration of 24 hours from the time of gauging they are to be placed in water, where they are to remain until tested.

The percentage, by weight, of water used in gauging, the temperature of the water, of the testing-room, and the gauged cement, to be recorded for reference.

*Other Tests.*

13. Pats of neat cement, 6 inches square and ⅜ of an inch thick, made on glass or other impervious substance, and placed under water as soon as set, and kept immersed, for seven days, or if tested in any other way that may be considered necessary by the inspector to test the soundness of the cement, shall show no cracking, flying, or alteration

of form. These pats of cement when broken are to show a section of uniform hardness and colour throughout.

*Specific Gravity.*

14. The specific gravity of the cement when fresh burned and ground to be not less than 3.15, or, when it can be proved to the satisfaction of the inspector that some time has elapsed since grinding, 3.10. Any cement of a less specific gravity than this minimum will be rejected.

*Chemical Analysis.*

15. A representative sample of the cement from each burning will be submitted to chemical analysis by the Admiralty inspector.

Should any of the samples of cement selected by the inspector for chemical analysis show that the cement contains more than 1½ per cent. of magnesia, 2 per cent. of sulphuric anhydride, or that the composition of the cement generally is of an unsatisfactory character, or is likely in any way to produce unsound work, the whole parcel of cement, which is represented by the samples will be rejected.

*No Consignments to be despatched without written order.*

16. No consignment of cement is to be despatched by the contractor without a written order to do so from the inspector.

*Delivery of the cement other than tested and passed by the Inspector, and deterioration in transit.*

17. The cement will also be examined and tested by the officer in charge of works after its delivery, and will be rejected if he can find that it is not in accordance with the contract, or unfit for use in the works.

Any cement delivered on the Admiralty premises may, if the officer in charge of works think fit, be at once emptied from the sacks, and spread out under cover on a proper floor, before being testified by him as specified.

If the cement has, before rejection, been delivered upon the Admiralty premises it must be removed from them by the contractor at his own expense, within one month of notice having been given to him by the officer in charge of works to remove the rejected cement, and if the cement has, before rejection, been emptied from the sacks in which it was delivered, the contractor must bear the expense of refilling it into the sacks.

All rejected cement must be at once replaced by the

contractor with other cement of a quality strictly in accordance with this specification.

*Meaning of specification. Decision of D.W. to be final and binding.*

18. Should any doubt arise as to the meaning of any part of this specification, or any difference arise with regard to matters of any kind relating to the carrying out of this contract between the officer in charge of works or inspector and the contractor, the matter in dispute is to be referred to the director of works, and his decision is to be final and binding on both sides.

*Transfer of contract.*

19. This contract, or any part, share or interest in it, is not to be transferred or assigned by the contractor, directly or indirectly, to any person or persons whomsoever without the written consent of the Admiralty.

*Wages.*

20. The wages paid in the execution of this contract shall be those generally accepted as current in each trade for competent workmen in the district where the work is carried out.

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LONDON COUNTY COUNCIL.—CEMENT TEST.

*Portland Cement.*

The whole of the cement for these works and herein referred to is to be highly-burnt pure Portland cement of the best quality, free from lime, slag, dust, or other foreign materials mixed with it after the cement has left the kiln. The cement, neat, must not set in less than one hour. It is to be ground so fine that the residue on a sieve of 5,800 meshes to the square inch (equal to about 76 per lineal inch) shall not exceed 10 per cent. of the whole by weight. Should this residue be exceeded, a quantity of fine ground cement, proportionate to such excess, must be added. When brought upon the works it is to be perfectly cool, and put into a dry shed or store which the Contractor is to provide for the purpose, sufficiently large to contain such a quantity of cement as the engineer may order to be kept in store.

*Shed.*

This shed is to be properly roofed and to have a wooden floor with sub-divisions of such size as the engineer may direct.

*Testing room.*

The contractor also to construct, to the engineer's satisfaction, a testing room properly roofed and fitted for its purposes.

The cement is to be spread out upon the floor of the shed above-mentioned in such separate quantities as may be directed, and is not to be used until it has been exposed to the air for a week and tested by samples taken from different parts.

*Neat test.*

The cement, when tested neat, is to be mixed with about 20 per cent. of water, and shall then be capable of sustaining a tensile strain of 400 lbs. per square inch seven days after being made into briquettes, during the last six days of which the briquettes have been immersed in water. At the expiration of 28 days the briquettes shall be capable of bearing a tensile strain of 550 lbs. per square inch, having been immersed in water during the last 27 days.

*Sand test.*

The cement, when tested with sand, is to be gauged with three times its weight of dry sand, which has passed through a sieve of 400, and been retained upon one of 900 meshes to the square inch. The cement and sand having been well mixed dry, about 10 per cent. of their weight of water is to be added, and briquettes formed in moulds of 1 inch sectional area at the weakest parts. The briquettes having in the meantime been kept in a damp atmosphere, are to be put into water 24 hours after they have been made, and shall remain in water 27 days more, when their tensile strength is to be tested by the engineer, by means of apparatus belonging to the council, and must bear, without breaking, a weight of 200 lbs. per square inch.

*Rate of testing.*

The strain is to be applied in all cases at the rate of 200 lbs. per minute.

*Chemical character. Specific gravity.*

Besides these mechanical tests, the cement will be tested as to its chemical character, and as to its specific gravity, which is not to be less than 3.10, and if not found satisfactory in every respect will be rejected.

To secure due progress the contractor shall, *immediately after the contract is signed,* procure and deliver on to the site of the works such a stock of cement as the engineer

shall order, and shall at all times during the progress of the works until their approaching completion *keep stored* on the work a quantity of cement as the engineer shall order.

*Cement mortar.*

The cement mortar used in these works to be mixed with not more than two equal measures of sand, and it shall not be re-used or re-mixed after it has become set.

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NEW SOUTH WALES.—SPECIFICATION FOR THE SUPPLY OF CEMENT REQUIRED FOR THE USE OF THE DEPARTMENT OF PUBLIC WORKS.

1. *Public Works Standard Test for Cement.*—For the purpose of making the following test, samples of cement will be selected by officers of the Government, such samples will be taken from one cask in every fifty casks, or from one bag in every 150 bags.

2. The appliances and materials for testing cement including standard sand, used in the Government Testing Room, can be seen and inspected there by contractors before tendering.

3. *Test No. 1—Hydraulicity.*—The cement, when gauged with water to a stiff paste, must set in a damp atmosphere in from one and a half hours to twelve hours. Neat cement of the consistency above mentioned will be made into pats, kept in moist air until set, and then placed in water at a temperature of between 65 deg. and 75 deg. Fahr., and also in Deval's hot bath at a temperature of 180 deg. Fahr. These test pats will be examined from day to day, and should they show symptoms of blowing, or any alteration or variation in form or volume, or imperfect setting capacity, the whole parcel from which the cement was taken may be rejected, and must (if delivered) be removed at the contractor's cost.

Notwithstanding that the cement may have set within the limit of time specified above, the Engineer (or architect, as the case may be) may reject such cement if the nature of the work on which it is proposed to be used requires a cement setting either slower or faster, as the case may be.

4. *Test No. 2—Weight.*—Each cask shall contain not less than 374 lb., and each bag not less than 125 lb. weight of cement, exclusive of packing, otherwise the deficiency

must be made up in quantity. The specific gravity to be not less than 3.00.

5. *Test No.* 3—*Fineness.*—The cement must be ground so fine that the residue on a sieve of 14,400 meshes per square inch, without rubbing, shall not exceed 15 per cent., and on a sieve of 32,400 meshes not more than 30 per cent.

6. *Test No.* 4—*Tensile Strength.*—For this test the cement will be gauged with three times its weight of standard sand (viz., sand from Nepean River, washed, dried, and sifted through a sieve of 400, and retained upon one of 900 meshes to the square inch), and mixed with a proportion of water, according to the regulations laid down for testing cement in the Public Works Department, and made into briquettes formed in moulds of 1 inch sectional area at the smallest part. Such briquettes to be kept thoroughly damp, and put into water twenty-four hours after they have been made, and remain in water at a temperature of between 65 deg. and 75 deg. Fahr. until their tensile strength is tested. These briquettes to bear a tensile stress of not less than 130 lb. per square inch seven days after gauging, and 200 lb. per square inch twenty-eight days after gauging. Cement when tested neat under the same conditions must bear a tensile stress of not less than 350 lb. to the square inch three days after gauging, and 450 lb. seven days after gauging, and 550 lb. twenty-eight days after gauging. Briquettes shall also, after being kept thoroughly damp for twenty-four hours, be kept in water at a temperature of 180 deg. Fahr. for seven days, when the tensile strength must be equal to that specified for twenty-eight days at normal temperature. The tensile stress will be ascertained by the Government testing machine, with the load increasing at the rate of 200 lb. per minute, and the average breaking weight of six briquettes will be taken for each test.

7. *Test No.* 5—*Free Lime.*—Any cement which absorbs in proportion more than two (2) milligrammes of *carbonic acid* to three (3) grammes of cement shall be taken as containing more than the permissible quantity of free lime.

*Conditions.*—The following conditions apply in all cases where contractors provide cement for works under contract for the Department:—

(1.) The cement used in the construction of all works

carried out by the several branches of the Public Works Department of New South Wales must also stand the foregoing tests; and subject to such tests contractors shall have the option of using or supplying either foreign or Colonial-made cement, subject, however, to the proviso in the next succeeding clause.

(2.) Cement which has passed the standard test when supplied to the Department, or used in the construction of works by the contractors, must be supplied or used in accordance with the terms and conditions of each respective contract; and in the case of brands which have shown deterioration in constructed works, the engineer (or architect as the case may be) shall, on reasons stated, have power to refuse their acceptance either before or after being tested and in any dispute as to the quality of cement, or anything relating thereto in connection with contracts, the decision of the engineer (or architect, as the case may be) shall be final.

(3.) In the event of the cement being rejected, all expenses and loss in freight, storing, handling, and removing such rejected cement is to be borne solely by the contractor.

(4.) Cement must be delivered in thoroughly sound condition, fit for immediate use, packed in strongly-made casks or bags; any damage to the packing, or any symptoms of staleness or of moisture having affected the cement, such as caking or partial setting, will cause the rejection of the casks or bags in which such damage or symptoms are found, and such casks or bags will not be accepted, and must be removed at the contractor's expense.

(5.) Should the sample fail in all or any of the above-mentioned tests, then the engineer (or architect, as the case may be) may reject the whole parcel from which the sample was taken; and if such rejected cement has been delivered on the site of any Government work, or on Government premises, the contractor shall at once remove the same at his own cost, failing which the engineer (or architect, as the case may be) may have it removed at the contractor's cost without further notice.

Samples taken from the centre of one cask in every 50 casks, for time of setting and condition in Deval's hot bath.

| No. of Cask. | Time of Setting. | |
|---|---|---|
| | Hours. | Minutes. |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
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DEPARTMENT OF PUBLIC WORKS,

# CEMENT

M.....of..... .....having applied to the Department of Cement manufactured by.....*ex* "..... ....." a sample of the by.....a Government Officer, and has been tested with the following *Work.*)

| Ref. No. | Description of Tests. | Results of Tests. |
|---|---|---|
| | **Neat cement set in** .. .. .. .. .. .. .. | Hours....Minutes ..... |
| 1 | | |
| 2 | Specific gravity .. .. .. .. .. .. .. .. | ..... .. ..... |
| 3 | Carbon Dioxide absorbed by 3 grammes of cement .. | Milligrammes..... ..... |
| 4 | Weight per cubic foot of set cement .. .. .. .. | lb. ..... |
| 5 | Residue on sieve of 14,400 meshes per square inch .. .. | per cent. ..... ..... |
| 6 | Residue on sieve of 32,400 meshes per square inch .. .. | ,, ..... |
| | **Neat cement, with.....per cent. of water** .. .. .. | |
| 7 | Tensile strength after 3 days in cold water .. .. .. | lb. per sq. in. ..... |
| 8 | Tensile strength after 7 days ,, .. .. . | ,, ,, ..... |
| 9 | Tensile strength after 7 days in Deval's hot bath . .. . | ,, ,, ..... |
| 10 | Tensile strength after 28 days in cold water .. .. . | ,, ,, ..... |
| | **1 of cement and 3 of sand with..... .....per cent. of water** .. .. .. .. .. .. .. .. .. .. .. | |
| 11 | Tensile strength after 7 days in cold water .. .. . | lb. per sq. in. ..... |
| 12 | Tensile strength after 7 days in Deval's hot bath .. .. | ,, ,, ..... |
| 13 | Tensile strength after 28 days in cold water .. .. .. | ,, ,, .. .... .... |
| 14 | Tensile strength after 3 months ,, .. .. .. | ,, ,, ..... |
| 15 | Tensile strength after 6 months ,, .. .. .. | ,, ,, ..... |
| 16 | Tensile strength after 12 months ,, .. .. .. | ,, ,, ..... |
| 17 | Pats of neat cement immersed in water after setting, and similar pats placed in Deval's hot bath and examined from day to day for constancy or variation of volume .. .. .. .. .. .. .. | ..... |
| 18 | Pats of neat cement kept in air to observe for colour .. | ..... |

NOTE.—The time occupied in making the briquettes on a non-absorbent bed is limited to ten the rest of the time in water: thence taken and immediately tested. Proportions of washed, dried, and sifted through sieve of 400 meshes per square inch, and caught machines, commencing with a stress equal to half the standard requirement, and briquettes is based on the amount absorbed by the cement in water under a pressure

Temperature of air while making briquettes.....°F.

Temperature of water in setting tank, from.....to.....°F.

NEW SOUTH WALES. No. of Test.....

# TEST.

Sydney.....190

Public Works for a test of.....casks of.....Brand of Portland bulk shipment which was stored at.....was on the.....selected result:—(*The Cement referred to is, however, not necessarily approved of for any Public*

| Standard Required. | Remarks. |
|---|---|
| Min., 1¼ hrs. ; max., 12 hrs. | |
| ,, 3·000<br>Max. 2·0 milligrammes. | |
| Max. 15 per cent.<br>,, 30 ,, | |
| Min. 350 lb. per sq. in.<br>,, 450 ,, ,,<br>,, 550 ,, ,,<br>,, 550 ,, ,, | |
| Min. 130 lb. per sq. in.<br>,, 200 ,, ,,<br>,, 200 ,, ,,<br>.....<br>.....<br>..... | |
| ..... | |
| ..... | [FOR DETAILS SEE OVER |

minutes, the briquettes are then kept in the moulds in a damp state for twenty-four hours, and cement, sand, and water ascertained by weight. Standard sand to be Nepean River sand, upon sieve of 900 meshes per square inch. Tensile strength ascertained by Adie's testing increasing at the rate of 200 lb. per minute. The percentage of water used in making the of 1,400 lb. per square inch.

Temperature of water used for mixing,..... ...°F

.....

Officer in charge of Cement Testing

| Degrees Fah. | Thermometric Curve while setting. Time in Minutes. 5 10 20 30 40 | DETAILS OF TENSILE TESTS. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Neat Cement. | | | | 1 of Cement and 3 of Sand. | | | | |
| | | Kept in Cold Water. | | | Kept in Hot Wat'r | Kept in C'id Wat'r | Kept in Hot Wat'r | Kept in Cold Water. | | |
| | | 5 Days. | 7 Days. | 28 Days. | 7 Days. | 7 Days. | 7 Days. | 28 Days. | 3 Months. | 6 Months. | 12 M'nths. |
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# INDEX.


| | PAGES. |
|---|---|
| Accelerated Tests | 105, 117 |
| Admiralty Specification | 125 |
| Adulteration | 98 |
| Aeration | 8, 107 |
| Aerometer | 73 |
| Alkalies | 51 |
| Alumina | 50, 52, 76, 77 |
| Analysis of Portland Cement | 49, 51, 113, 129 |
| Analysis of Raw Materials | 24 |
| Arnold's Press | 90 |
| Bauschinger's Test for Variation of Volume | 110 |
| Bohmé Hammer | 91 |
| Boiling Test | 103, 106 |
| Briquette Making | 89, 90, 97 |
| Burning Raw Materials | 23, 34–42 |
| Calcimeters Faija's | 27–29, 31 |
| „ Scheibler's | 31–33 |
| Calcining | 34–42 |
| Canadian Society of Engineers Specification | 119 |
| Carbonate of Lime | 11, 12, 21, 24, 27–33 |
| Cement Gauger | 97 |
| Chalk | 14 |
| Chemical Formula | 8 |
| Chemistry of Portland Cement | 8, 49 |
| Clay | 17 |
| Clinker | 37 |
| Coke Ash | 57 |
| „ „ Analysis | 51 |
| Composition of Cement | 11 |
| Compression Tests | 99–102 |
| Constancy of Volume | 109 |
| Contraction | 67, 69, 107 |
| Cost of Production | 2 |
| Crazing in Cement Work | 108, 109 |
| Description of Portland Cement | 6 |
| Deval Test | 107, 135 |
| Dry Process of Manufacture | 18, 20, 23 |
| Estimation of Raw Materials | 27–33 |
| Expansion | 104, 107 |
| Faija's Hot Test | 105, 111 |
| Fineness | 45, 46, 47, 57, 64–74, 116, 118, 119, 121, 124, 128, 133 |
| Flour | 65, 66, 69 |
| Flourometer | 72, 73 |
| Foreign Competition | 1, 3 |
| Free Lime | 8, 50, 66, 107 133 |

PAGES

Gilmore Needles .. .. .. .. .. .. 82
Goodman's Cement Setter .. .. .. .. .. 82
Gravimeter (Mann's) .. .. .. .. .. .. 60
Grinding .. .. .. .. .. .. 43–48
„ (Stones) .. .. .. .. .. .. 43
„ (Ball Mill) .. .. .. .. .. 43, 45
„ (Tube Mill) .. .. .. .. .. 43, 45
„ (Griffin Mill) .. .. .. .. .. .. 46
„ (Kominor Mill) .. .. .. .. .. 46
Gypsum .. .. .. .. .. .. 51, 76, 77

History of Portland Cement .. .. .. .. .. 1, 6
Hot Water Test .. .. .. .. .. .. 105
Hydraulic Index .. .. .. .. .. .. 8
Hydraulicity .. .. .. .. .. .. 50, 132

India Office Specification .. .. .. .. .. 123
Iron .. .. .. .. .. .. .. 50, 52

Kilns .. .. .. .. .. .. .. 34–42
„ (Bottle) .. .. .. .. .. 34–35
„ (Chamber) .. .. .. .. .. .. 35
„ (Continuous) .. .. .. .. .. .. 37
„ (Dietzsch) .. .. .. .. .. .. 38
„ (Schneider) .. .. .. .. .. .. 40
„ (Rotary) .. .. .. .. .. 20, 40, 41

Lime .. .. .. .. .. .. .. 19, 50, 53
Lime, Estimation of .. .. .. .. .. .. 56
London County Council Specification .. .. .. 129

Magnesia .. .. .. .. .. .. 17, 51, 54

New South Wales Government Specification .. 132–138

Overlimed Cements .. .. .. .. .. 88, 104
Overclayed Cements .. .. .. .. .. 104, 107
Oxide of Iron .. .. .. .. .. .. 50, 52

Pats .. .. .. .. .. 104, 105, 106, 120, 128
Portland Cement .. .. .. .. 6, 14, 121, 130

Quick Setting Cement .. .. .. .. .. 66, 75

Raw Materials .. .. .. .. .. 11–17
Raw Materials, Mixing .. .. .. .. 12, 18, 20
„ „ (Thames and Medway) .. .. .. 12
„ „ (Lias) .. .. .. .. .. .. 12
„ „ (Cambridgeshire) .. .. .. 12, 13, 14
Residue .. .. .. .. .. .. 65, 66, 69

Sand Tests .. .. .. 65, 88, 89, 117, 119, 120, 131
Setting .. .. .. .. 7, 66, 75–86, 119, 127

| | PAGES |
|---|---|
| Sieving | 70, 71, 72 |
| Silica | 17, 50, 52 |
| Soundness | 103–109, 118, 119, 120, 122 |
| Specifications | 3, 115–138 |
| Specific Gravity | 57–63, 120, 129, 131 |
| " " (Flask) | 63 |
| Standard Wire Gauge | 71 |
| Steam Tests | 66 |
| Sulphates | 17 |
| Sulphuric Anhydride | 51, 55 |
| Temperature | 78 |
| Tensile Strain 6, 19, 87-98, 118, 119, 120, 121, 122, 124, 128, 131, 133 | |
| Tensile Strain, Divergent Results | 87, 95, 96 |
| Testing Machines— | |
| Adie | 92 |
| Michaelis | 94 |
| Faija | 95 |
| Fairbanks | 101 |
| Titration | 27 |
| Uses of Cement | 4–6 |
| Variation of Volume | 103–109 |
| Vicat Needle | 82 |
| Volumenometer (Blount's) | 61, 62 |
| War Office Specification | 121 |
| Wash Mills | 18 |
| Weight of Cement | 57–63, 122, 127 |
| Wet Process Mixing | 18–20 |
| World's Cement Production | 8 |

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